Woods Hole Oceanographic Institution

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Technical Report
January 1995

Arabian Sea Mixed Layer Dynamics Experiment

Mooring Deployment Cruise Report

R/V *Thomas Thompson* Cruise Number 40

11 October - 25 October 1994

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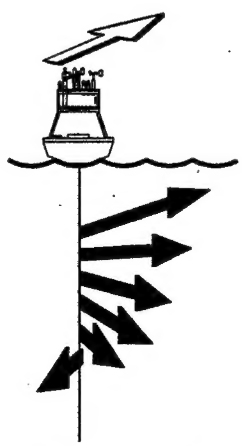

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UOP Technical Report 95-1

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Approved for Distribution:

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Abstract

An array of surface and subsurface moorings were deployed in the Arabian Sea to provide high quality time series of local forcing and upper ocean currents, temperature, and conductivity in order to investigate the dynamics of the ocean's response to the monsoonal forcing characteristic of the area. The moored array was deployed during R/V *Thomas Thompson* cruise number 40.

One Woods Hole Oceanographic Institution (WHOI) surface mooring, two Scripps Institution of Oceanography (SIO) surface moorings and two University of Washington (UW) Profiling Current Meter moorings were deployed. The moorings were deployed for a period of one year beginning in October 1994 as part of the Office of Naval Research (ONR) funded Arabian Sea experiment. Two six month deployments were planned. The moorings were deployed at 15.5°N 61.5°E (WHOI), 15.7°N 61.3°E (SIO), 15.3°N 61.3°E (SIO), 15.7°N 61.7°E (UW), and 15.3°N 61.7°E (UW).

The WHOI surface mooring was outfitted with two meteorological data collection systems. A Vector Averaging Wind Recorder (VAWR) and an IMET system made measurements of wind speed and direction, sea surface temperature, air temperature, short wave radiation, long wave radiation, barometric pressure, relative humidity and precipitation. Subsurface instrumentation included Vector Measuring Current Meters (VMCMs), Multi-Variable Moored Systems (MVMS), conductivity and temperature recorders and single point temperature recorders.

Expendable bathythermograph (XBT) data and CTD data were collected while in transit to the site and between mooring locations.

This report describes in a general manner the work that took place during R/V *Thomas Thompson* cruise number 40 which was the initial deployment cruise for this moored array. A detailed description of the WHOI surface mooring and its instrumentation is provided. Information about the XBT and CTD data collected during the cruise is also included.

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Section I: Introduction

Cruise number 40 of the R/V *Thomas Thompson* (TN040) departed Muscat, Oman, on 11 October 1994 at 0300 UTC. The purpose of the cruise was to deploy one Woods Hole Oceanographic Institution (WHOI) surface mooring, two Scripps Institution of Oceanography (SIO) surface moorings and two University of Washington (UW) subsurface Profiling Current Meter (PCM) moorings. All five moorings were part of the Office of Naval Research (ONR) funded Arabian Sea experiment. This was the first of three cruises associated with servicing the array of moorings. A turnaround cruise is planned for April 1995 at which time the surface moorings will be recovered and redeployed. The final recovery of all moorings is planned for October 1995. The mooring deployment schedule is shown in Figure 1.

The cruise involved personnel from the Woods Hole Oceanographic Institution (WHOI), Scripps Institution of Oceanography (SIO), University of Southern California (USC), Lamont Doherty Earth Observatory (LDEO), University of Washington (UW), University of South Florida and Texas A and M University. Appendix 1 lists the cruise participants. Figure 2 shows the cruise track and the mooring locations. Table 1 lists the positions of the moorings deployed during this cruise.

While enroute to the mooring array site hourly XBT data were collected. During the bathymetric survey that preceded the mooring deployments XBT data were collected every 15 minutes. The XBT positions appear in Appendix 2. A total of 61 CTD casts were made throughout the cruise. The last thirty five casts were done in a tow yo fashion between the surface and 300 meters depth as the ship transitted northward from the southern part of the moored array. Appendix 3 contains the CTD positions, start times and maximum depth of the stations.

This report has in addition to this introduction three sections. The second section primarily describes the WHOI mooring and the instrumentation that was deployed on the WHOI mooring. The third section is a chronology of the entire cruise.

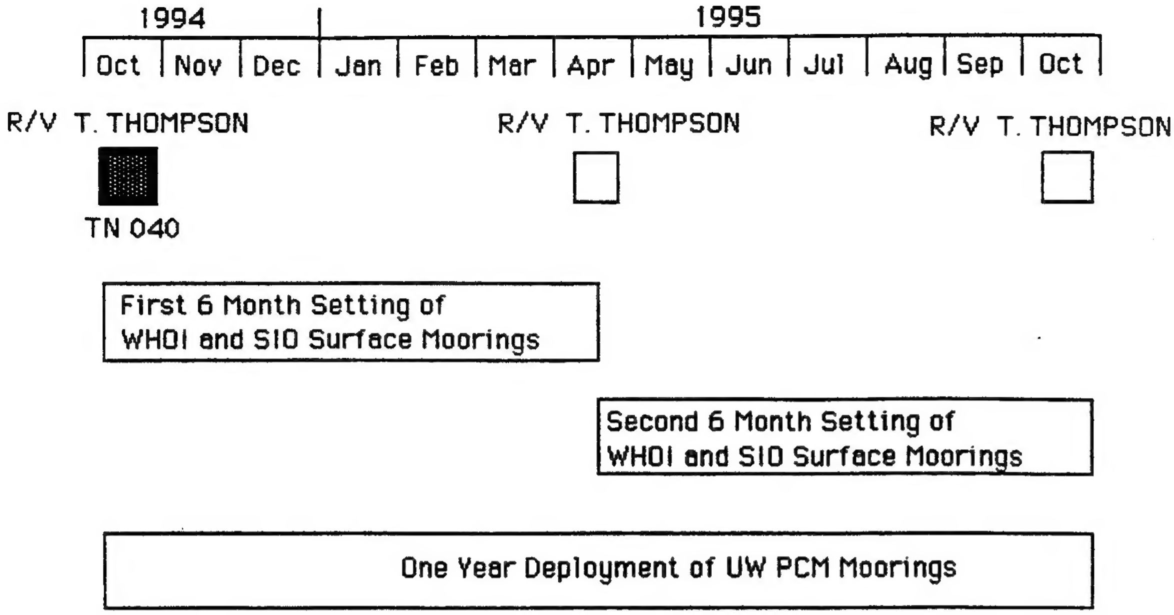


Figure 1. Arabian Sea mooring cruise schedule.

Table 1. Arabian Sea Mooring Deployment Information

Mooring	WHOI Reference #	Deployment Date and Time	Anchor Position
WHOI Discus Buoy	969	15 October 1994 @1048 UTC	15°30.04'N 61°29.99'E
SIO Northern Buoy		17 October 1994 @0723 UTC	15°43.53'N 61°15.94'E
SIO Southern Buoy		18 October 1994 @0649 UTC	15°16.53'N 61°16.11'E
UW Northern PCM	972*	20 October 1994 23 October 1994	15°43.90'N 61°44.53'E
UW Southern PCM	970	19 October 1994	15°16.37'N 61°44.07'E

The first deployment (WHOI reference #271) of the Northern PCM mooring was on 20 October 94 at position 15°43.75'N, 61°43.95'E. It was recovered on 22 October 94 at approximately 1100 UTC in order to correct for a depth recorder error. The redeployment is as shown above.*

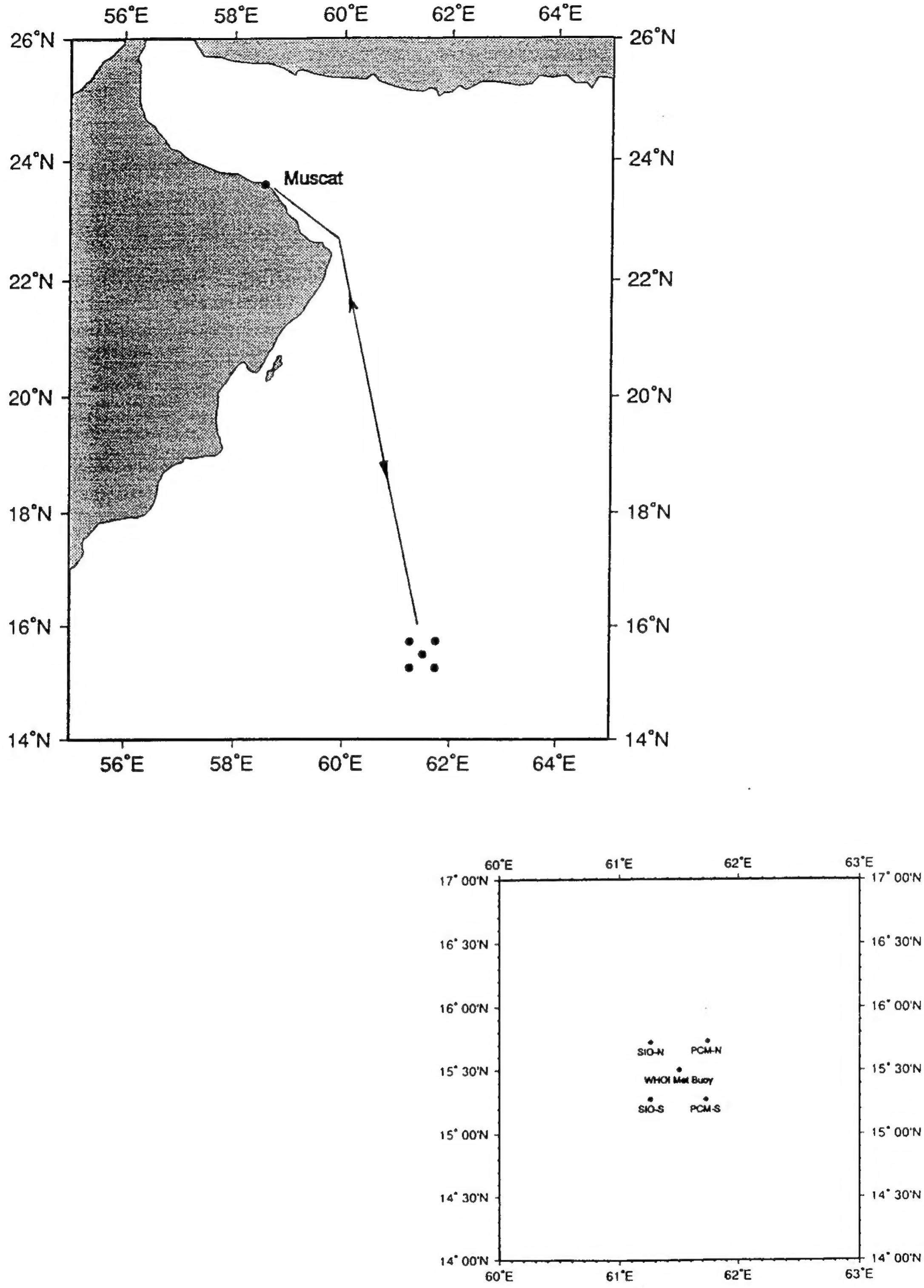


Figure 2: Cruise track and mooring locations.

Section II: The Moored Array

Five moorings were deployed during cruise number 40 of the R/V *Thomas Thompson*. The central mooring in the array was a WHOI / Upper Ocean Processes (UOP) group surface mooring with meteorological and oceanographic instrumentation. The WHOI mooring will be described in greater detail in the following sections. To the west of the WHOI mooring were two SIO surface moorings utilizing 7'-6" diameter toroid shaped buoys for their primary flotation. The buoys were outfitted with a tower that contained two redundant meteorological systems measuring wind speed and direction, air temperature, sea surface temperature, short wave radiation, and barometric pressure. The subsurface instrumentation on each SIO mooring included a downward looking ADCP mounted in the buoy bridle and 10 temperature recorders mounted on the wire in the upper 150 meters. The SIO moorings were given a north and south designation. To the east of the WHOI surface mooring there were two University of Washington subsurface profiling current meter moorings. These were also given a north and south designation. The PCM was designed to cycle between 26 and 202.5 meters. Both PCM moorings had a WHOI temperature logger mounted on the top sphere of the mooring at approximately 20 meters and another at approximately 250 meters depth. The southern PCM mooring also had five WHOI VMCMs at approximately 300, 500, 750, 1500, and 3000 meters depth. Figure 3 schematically shows all five moorings and the location of the subsurface instrumentation.

A. WHOI Surface Mooring

The WHOI mooring deployed in the Arabian Sea is shown schematically in Figure 4. The surface buoy is a three meter diameter discus shaped buoy with a two part aluminum tower and rigid bridle. Eighteen meteorological sensors are mounted on the top half of the buoy tower and are described in the following section. Eleven near-surface oceanographic sensors are attached to the bridle and buoy hull.

The mooring is an inverse catenary design utilizing chain, wire rope, nylon and polypropylene and has a scope (Scope = slack length/water depth) of 1.22. In addition to the buoy mounted instruments the mooring supports an additional 27 recording packages, some of which have multiple sensors.

The design of the Arabian Sea mooring took into consideration the high wind and sea state conditions expected during the monsoons. It is believed that the static and dynamic loads that the Arabian Sea surface mooring will experience are of such magnitude and duration that conventional designs used successfully in the past in more benign environments may not last in the Arabian Sea. This is because the dynamic loading may be so severe that ultimate strength considerations are superseded by the fatigue properties of the standard hardware components.

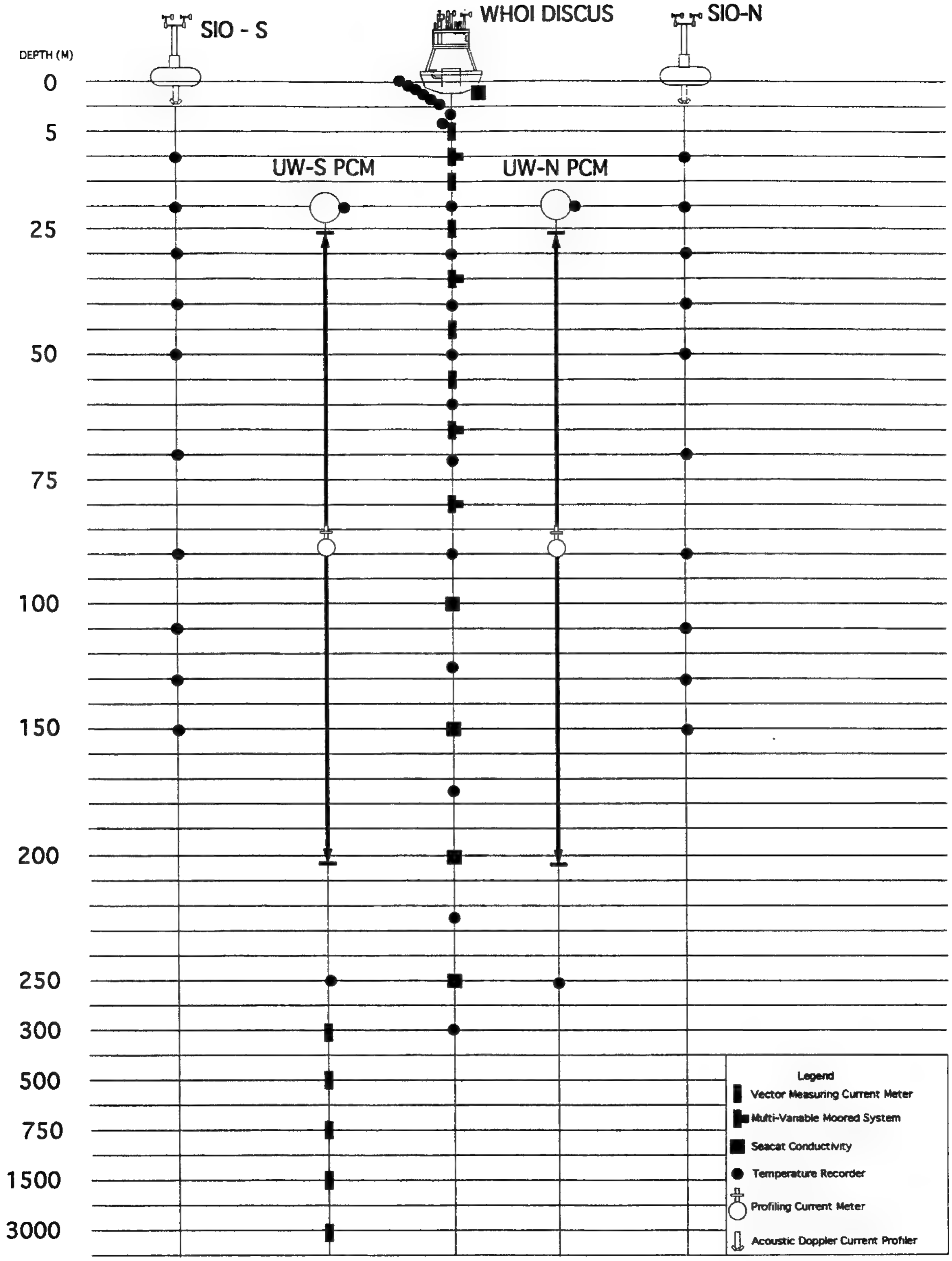


Figure 3: Arabian Sea moored array instrument locations.

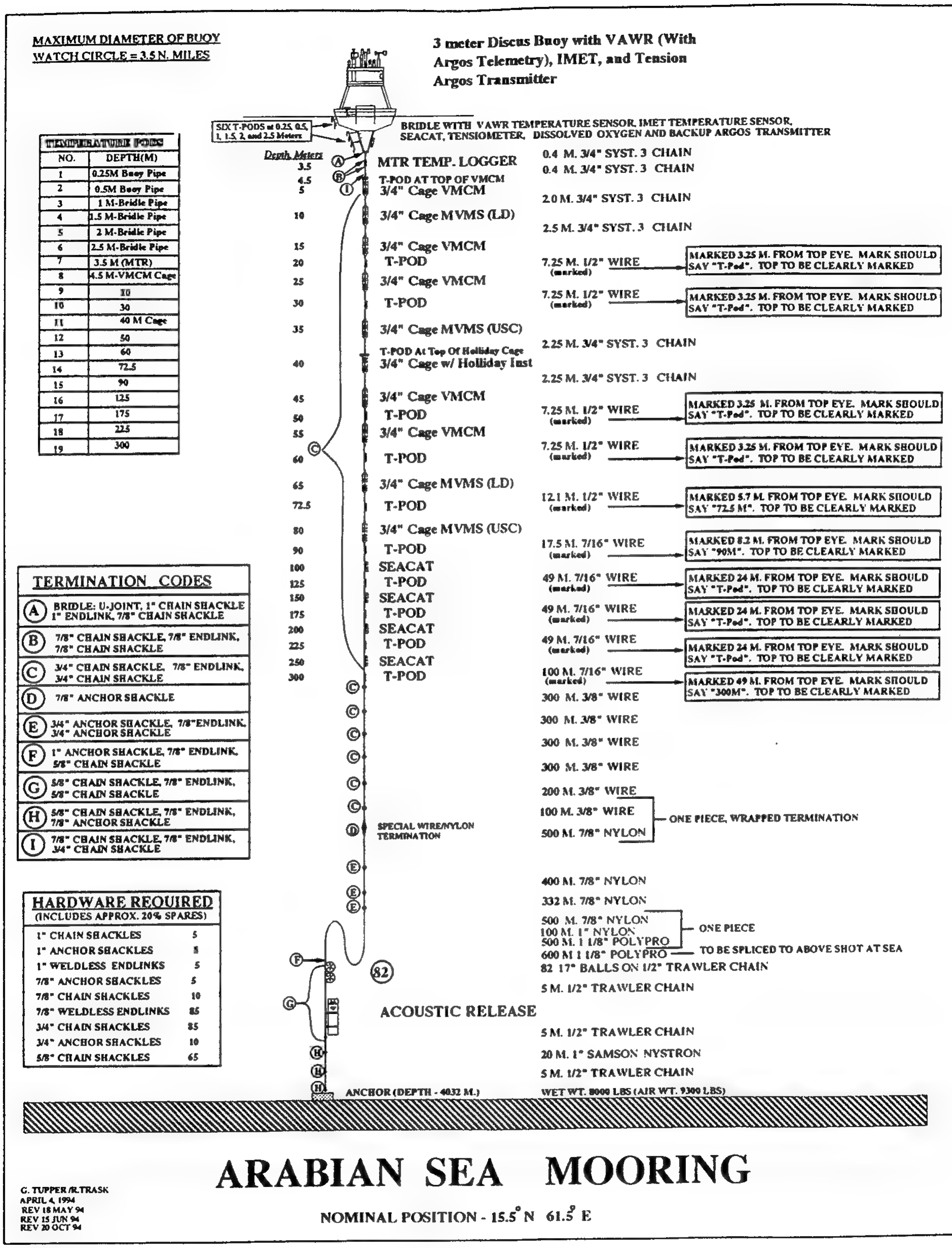


Figure 4: WHOI surface mooring schematic.

During the mooring design process cyclic fatigue tests were conducted on pear rings, shackles, wire rope, load cages, and chain to study the fatigue life of these various components. The fatigue tests showed that weldless sling links also known as pear rings have a relatively short fatigue life when cycled with tensions that a mooring in the Arabian Sea might experience. These components were replaced by 7/8" weldless end links which faired very well during the fatigue tests. In the same manner 3/4" shackles were found to have marginal fatigue characteristics when subjected to the expected tensions. By shot peening the 3/4" shackles their fatigue performance improved greatly.

Shot peening is a process whereby a component is blasted with small spherical media called shot in a manner similar to the process of sand blasting. It differs from sand blasting in that the media used in shot peening is more rounded rather than angular and sharp as in sand blasting. Each piece of shot acts like a small ball peen hammer and tends to dimple the surface that it strikes. At each dimple site the surface fiber of the material is placed in tension. Immediately below the surface of each dimple the material is highly stressed in compression so as to counteract the tensile stress at the surface. A shot peened part with its many overlapping dimples therefore has a surface layer with residual compressive stress. Cracks do not tend to initiate or propagate in a compressive stress zone. Since cracks usually start at the surface, a shot peened component will take longer to develop a crack thereby increasing the fatigue life of the part. Many materials will also increase in surface hardness due to the cold working effect of shot peening.

The compressive stresses introduced by shot peening increase the resistance to fatigue failures, corrosion fatigue, stress corrosion cracking, hydrogen assisted cracking, fretting, galling, and erosion caused by cavitation. The benefits of cold working include work hardening, and intergranular corrosion resistance.

Another in-line component that was reviewed during the design process was the load cages of the VMCM. Cage fabrication specifications were found to be so loosely defined that there was potential for considerable variability from cage to cage. With the help of Stonebridge Corporation the appropriate welding specifications were identified. In addition it was felt that dye penetrant inspection of all welds by a certified inspector would provide a level of quality control not present in our existing cages. For new fabrication, certification of the origin of the material was added.

Stonebridge also provided assistance in designing a gusset to be welded between the longitudinal members and the end bales to stiffen the cage and improve its fatigue life. Gussets were retrofitted to the existing WHOI VMCM cages by Stonebridge Corp. While the cages were being outfitted with gussets they also had their welds brought up to specification and dye penetrant inspected. New cages were fabricated for the MVMS and bio-acoustic instruments according to the new specifications.

B. WHOI Instrumentation

A total of 37 recording instruments with 95 sensors were deployed on the WHOI surface mooring. There were two meteorological systems, nine current meters (four with bio-optical sensors), 19 temperature data loggers, five conductivity recording instruments, one tension recorder and one bio-acoustic instrument. The specific instrumentation deployed during this cruise is shown in Table 2. Appendix 4 has a complete listing of all WHOI instrumentation that was deployed during TN 40. The listing shows for each instrument type the serial number, on which mooring it was deployed and at what depth.

1. Meteorological Instrumentation

The WHOI discus buoy was outfitted with two separate meteorological packages. One system was Vector Averaging Wind Recorder which logged and telemetered data from eight meteorological sensors. The second meteorological data recording system called IMET (for Improved METeorological measurements) logged data from nine meteorological sensors. A third instrument made an independent measurement of relative humidity and temperature and recorded the data internally. All three systems are described in detail below.

a. Vector Averaging Wind Recorder

One of the two meteorological units mounted on the 3 meter discus buoy is a Vector Averaging Wind Recorder (VAWR). The VAWR is configured to measure wind speed, wind direction, short wave radiation, long wave radiation, relative humidity, barometric pressure, air temperature, and sea surface temperature.

Recording on a digital cassette tape the VAWR is sampling at a 7.50 minute rate. Table 3 shows the type of sensors used for the meteorological measurements and the sampling scheme.

Data from the VAWR is being telemetered via satellite back to WHOI through Service Argos. The VAWR ARGOS transmitter has three PTT I.D. numbers for data transmission, one of which is used for obtaining position information.

The standard temperature range typically used in the VAWR is 0–30°C. This range was modified to be 0 to 35°C for the Arabian Sea experiment due to the expected high temperatures.

The VAWR sea surface temperature (SST) sensor was mounted on the bridle at a depth of one meter. A continuous length of was run from the VAWR to the buoy deck and then down to the bridle mounted SST sensor via an external aluminum pipe

Table 2
Arabian Sea Experiment
Moored Array Instrumentation

DEPTH (meters)	SIO-S	UW-S PCM	WHOI	UW-N PCM	SIO-N
0.25			T-3836		
0.5			T-3662		
1			T-4483		
1			SST V721WR		
1			IMET SST		
1.5	ADCP 167		T-5432		ADCP 195
1.5			T-3667		
1.5			SEACAT 1179		
1.5			Dissolved Oxygen		
2			T-3839		
2.5			T-3762		
3.5			MTR-3240		
4.5			T-3763		
5			VM-011		
10	SIO T-3270		LD MVMS 302703		SIO T-3294
15			VM-037		
20	SIO T-3715	T-3265	T-3259	T-3279	SIO T-3306
25			VM-039		
30	SIO T-3281		T-3305		SIO T-3276
35			USC MVMS 500501		
40	SIO T-3307		BIO-ACOUSTIC		SIO T-3708
40			T-3703		
45			VM-033		
50	SIO T-3713		T-4489		SIO T-3314
55			VM-015		
60			T-4487		
65			LD MVMS 401405		
70	SIO T-3706				SIO T-3282
72.5			T-4481		
80			USC MVMS 500601		
90	SIO T-3295		T-3301		SIO T-3714
100			SEACAT 357		
110	SIO T-3278				SIO T-3275
125			T-4491		
130	SIO T-3277				SIO T-3304
150	SIO T-3292		SEACAT 0994		SIO T-3310
175			T-3761		
200			SEACAT 992		
225			T-4493		
250		T-2537	SEACAT 993	T-2541	
300		VM-016	T-2534		
500		VM-018			
750		VM-021			
1500		VM-025			
3025		VM-038			

Legend:

T-####	WHOI Temperature Recorder
SIO T-####	SIO Temperature Recorder
Seacat ###	Seacat Conductivity and Temperature Recorder
ADCP ###	SIO Acoustic Doppler Current Profiler
Bio Acoustic	Tracor Science Applications Bio Acoustic Instrument
USC MVMS ######	University of Southern California Multi-Variable Moored System
LD MVMS ######	Lamont Doherty Earth Observatory Multi-Variable Moored System
MTR-####	WHOI Temperature Recorder

Table 3. VAWR Sensor Specifications

Parameter	Sensor Type	Accuracy	Record Time
Wind Speed	R.M. Young 3-cup Anemometer	+/- 2% above 0.7 m/s	Vector Averaged
Wind Direction	Integral Vane w/vane follower WHOI/EG&G	+/- 1 bit 5.6 degrees	Vector Averaged
Insolation	Pyranometer Eppley 8-48	+/- 3% of reading	Averaged
Long Wave Radiation	Pyrgeometer Eppley PIR	+/- 10%	
Thermopile	PIR		Averaged
Body Temp.	10K @ 25 deg. C		Note 4
Dome Temp.	10K @ 25 deg. C		Note 5
Relative Humidity	Variable Dielectric Conductor Vaisala Humicap 0062HM	+/- 2% RH	3.515 Sec. Sample Note 1
Barometric Pressure	Quartz crystal Digiquartz Paroscientific Model 215,216	+/- 0.2 mbars wind < 20 m/s	2.636 Sec. Sample Note 1
Sea Temperature	Thermistor Thermometrics 4K @ 25 degrees C	+/- 0.005 degrees C	Note 2
Air Temperature	Thermistor Yellow Springs #44034 5K @ 25 degrees C	+/- 0.2 degrees C wind > 5 m/s	Note 3

Notes:
1. Relative Humidity and Barometric Pressure are burst samples taken in the middle of the recording interval.
2. Sea temperature is measured during the first quarter of the recording interval, for one quarter of the record time.
3. Air temperature is measured during the second quarter of the recording interval, for one quarter of the record time.
4. LWR body temperature is measured during the third quarter of the recording interval, for one quarter of the record time.
5. LWR dome temperature is measured during the fourth quarter of the recording interval, for one quarter of the record time.

mounted on the side of the buoy to protect the cable. This method eliminates the need for multiple bulkhead connectors which can affect the temperature reading.

The VAWR deployed in the Arabian Sea experiment was modified to measure and record several long wave radiation parameters. The outputs from the thermopile, dome temperature and body temperature were recorded by the VAWR.

Wind tunnel tests have shown that the cage bars of the VAWR wind sensor have caused the vane to be offset, depending upon where the vane was in relation to the cage bars. If the vane was oriented such that it was in close proximity to one of the cage bars the turbulence around the bar tended to offset the vane from its true direction.

The findings of these tests and recent experience with one instrument from another experiment that was missing a vane upon recovery brought about some changes to the VAWR vane for the Arabian Sea experiment. The length of the vane was shortened to 6.5". The general shape of the vane however, was not changed. The pivot rod was slotted so that the edge of the vane could be inserted. Nylon pins were inserted through the pivot rod and the vane to secure the vane to the bar. Two part epoxy was used as a filler to smooth the transition between the pivot bar and the vane as well as to provide extra strength to the joint.

The vane cage bars for the Arabian Sea experiment VAWR were inclined such that when viewed from above it appears as if the top had been rotated clockwise relative to the bottom plate. The VAWR was mounted on the buoy such that the VAWR lubber line is not perpendicular to the front face of the buoy. It was rotated approximately 15° in a clockwise direction so as to offset the location of the rear cage bar.

Prior to shipment to Oman the air and sea temperature sensors as well as the relative humidity sensors were calibrated at WHOI. The calibrations of the barometric pressure sensors were checked at WHOI and if found out of specification were returned to the manufacturer for recalibration. The short wave and long wave radiation sensors were calibrated by the manufacturer. The wind direction sensor readings were compared with a known bearing to a fixed target both at WHOI and in Muscat. After reviewing the initial direction comparison data collected in Muscat the VAWR vane doughnut that holds the magnets was rotated approximately 5 degrees clockwise. The buoy was then rechecked and the data compared favorably with the known heading and the IMET system. Details of the direction comparison tests can be found in Appendix 5. In addition the meteorological instruments were run on the buoy for two months prior to shipment to burn in all systems and work out the bugs. The data was compared with standards at WHOI.

b. IMET Meteorological System

The IMET meteorological sensor system for the Arabian Sea WHOI surface buoy consists of nine IMET sensor modules. The modules measure the following parameters:

1. Relative humidity with temperature;
2. Barometric pressure;
3. Air temperature (RM Young passive shield);
4. Air temperature (aspirated shield);
5. Sea surface temperature;
6. Precipitation;
7. Wind speed and direction;
8. Short wave radiation;
9. Long wave radiation.

All IMET modules for the Arabian Sea were modified for low power consumption so that a non-rechargeable alkaline power pack could be used.

The data logger for the system is based on an Onset Computer Corp. Model 7 Tattletale computer with hard drive, also configured and programmed with power conservation in mind. An associated interface board ties the Model 7 via individual power and RS-485 communications lines to each of the 9 IMET modules.

The following IMET modules and their associated software were deployed on the WHOI discus buoy.

Module	Software version used
HRH #111	IMETHRH v2.2
WND #104	IMETWND v2.0
LWR #101	IMETLWR v2.0
SST #106	IMETTMP v2.0
TMP #101	IMETTMP v2.0
SWR #109	IMETSWR v2.1
BPR #107	IMETBPR v2.0
PRC #101	IMETPRC v2.1
TMP #108 (ASPIRATED)	IMETTMP v2.0
LOGGER #226	LOGGER10 v1.5

Several problems were encountered while preparing the IMET instrumentation in Muscat, Oman. During the first attempt to verify correct wind direction output by rotating the buoy, an apparent problem was identified with the vane readings. They would either lock up or would not swing through all 360 degrees. Both the primary

and spare wind modules exhibited the same problem in test mode. The problem was fixed by revising the IMETWND firmware to re-initialize the 8255 parallel port on each cycle of the test mode (this periodic re-initialization was already present during normal operations). The wind direction readings were compared with a known bearing to a fixed target in Muscat. Details of the direction comparison tests can be found in Appendix 5.

The relative humidity module shield support plate was found cracked. The entire shield assembly was replaced with the shield assembly from the spare humidity module.

After connecting the sea surface temperature (SST) module to the system the SST data showed several gaps. The SEACON cable from the SST module to the bottom access plate bulkhead connector was intermittent at the female end. Since a spare was not available a new female pigtail was spliced to the original cable.

IMET Sampling Scheme

The logger polls all modules at one minute intervals (takes several seconds) and then goes to low power sleep mode for the rest of the minute. Data is written to disk once per hour.

The air temperature, sea surface temperature, barometric pressure, relative humidity, longwave radiation and precipitation modules take a sample once per minute and then go to low power sleep mode for the rest of the minute.

The short wave radiation module takes a sample every 10 seconds and produces a running one minute average of the six most recent samples. It goes to low power sleep mode between 10 second samples.

The vane on the wind module is sampled at one second intervals and averaged over 15 seconds. The compass is sampled every 15 seconds and the wind speed is averaged every 15 seconds. East and north current components are computed every 15 seconds.

Once a minute the logger stores an average east and north component that is an average of the most recent four 15 second averages. In addition average speed from four 15 second averages is stored, along with the maximum and minimum speed during the previous minute, average vane computed from four 15 second averages, and the most recent compass reading.

c. Stand Alone Relative Humidity / Temperature Instrument

A self contained relative humidity and temperature instrument was mounted on the tower of the WHOI discus buoy. This instrument, developed and built by members of the Upper Oceans Processes Group, takes a single point measurement of both relative humidity and temperature at a desired record interval. The sensor used is a Rotronics MP-100. The relative humidity and temperature measurements are made inside a protective Gortex shield. The logger is an Onset Computer Corp. model 4A Tattletale with expanded memory to 512K. The unit is powered by its own internal battery pack.

The mechanical housing is PVC pipe which has been machined to accept end caps with an oring seal. A multi-plate radiation shield protects the sensors from direct sunlight and is similar to that used on the VAWR relative humidity sensor. The recording interval was set to 3.75 minutes for the Arabian Sea experiment.

The height (and depth) of the buoy and bridle mounted instrumentation (relative to the buoy deck) can be found in Table 4. The predicted water line on the buoy is approximately 0.3 meters below the buoy deck but will be accurately measured when the buoy is recovered.

2. Subsurface Instrumentation

a. Buoy Tension Recorder

Buoy tension was measured at the base of the buoy bridle using a DJ Instruments Co. tension cell and recorded using an Onset Computer Corp. Model 6 Tattletale. The tension cell was rated from 0 to 10,000 pounds. The sampling rate for tension in a 12 hour period beginning at 0000 and 1200 UTC is as follows:

45 minutes of 4 Hz tension.
15 minutes of 20 second max/min/average of 4 Hz tension.
11 hours of 20 second max/min/average of 4 Hz tension.
This is repeated every 12 hours for a 48 hour cycle. The data is then stored to a hard disk on the Tattletale.

An Argos transmitter is connected to the tension logger so that a single point tension measurement is included with every transmission. Position information is obtained from Service Argos based on these tension transmissions.

b. Sub-Surface Argos Transmitter

An NACLS Inc. Subsurface Mooring Monitor (SMM) is mounted upside down on the bridle of the discus buoy as a backup recovery aid in the event that the mooring parts and the buoy flips upside down. The SMM has an internal mercury switch which

Table 4. **Sensors mounted on the WHOI surface buoy and their elevation relative to the buoy deck.**

Parameter	Sensor ID	Elevation relative to buoy deck (meters)	Measurement Location
VAWR	V721WR		
Air Temp	Therm. 5804	2.30	Mid shield
Relative Hum	V-034-001	2.31	Mid shield
Barom. Press	S/N 46398	2.38	Center of Port
Wind Speed	V721WR	2.98	Center of cups
Wind Direction	V721WR	2.69	Mid Vane
Short Wave	S/N 25418	3.04	Base of dome
Long Wave	S/N 28463	3.04	Base of dome
Sea Temp	Therm. 5005	-1.30	End of Probe
IMET	Logger No. 226		
Air Temp	TMP #101	2.36	Mid Shield
Relative Hum	HRH #111	2.36	Mid Shield
Barom. Press	BPR #107	2.39	Center of Port
Wind Speed	WND #104	2.78	Prop Axis
Wind Direction	WND #104	2.78	Prop Axis
Short Wave	SWR #109	3.04	Base of dome
Long Wave	LWR #101	3.04	Base of dome
Precipitation	PRC #101	2.76	Top of Funnel
Sea Temp	SST #106	-1.27	Tip of probe
Aspirated Air Temp	TMP #108	1.82	Openning of port
Stand alone RH w/ temp	#002	2.60	Mid Shield
Seacat	S/N 1179	-1.80	At Temp Probe
Dissolved Oxygen	No. 60	-1.80	Sensor end
T-POD	5432	-1.75	Thermistor end
T-POD	3836	-0.55	Thermistor end
T-POD	3662	-0.81	Thermistor end
T-POD	4483	-1.30	Thermistor end
T-POD	3667	-1.79	Thermistor end
T-POD	3839	-2.29	Thermistor end
T-POD	3762	-2.78	Thermistor end

(-) indicates distance below buoy deck

Nominal distance between buoy deck and water line is .3 meters

turns an Argos transmitter on when the unit is upright. If the mooring parted and the buoy became unstable and flipped upside down the Argos transmitter would switch on and the buoy position could be tracked.

c. SEACAT Conductivity and Temperature Recorders

There were five Seabird Seacats conductivity and temperature recorders deployed on the WHOI surface mooring. The shallowest Seacat was mounted directly to the bridle of the discus buoy. The other four were mounted on in-line tension bars and deployed at 100, 150, 200, and 250 meters depth.

The Seacat takes a single point measurement of salinity and temperature at the desired sample rate. On the UOP mooring the Seacats were set to sample every 7.50 minutes.

d. Dissolved Oxygen Sensor

A LDEO self powered internally recording dissolved oxygen instrument was mounted to the buoy bridle at 1.5 meters depth.

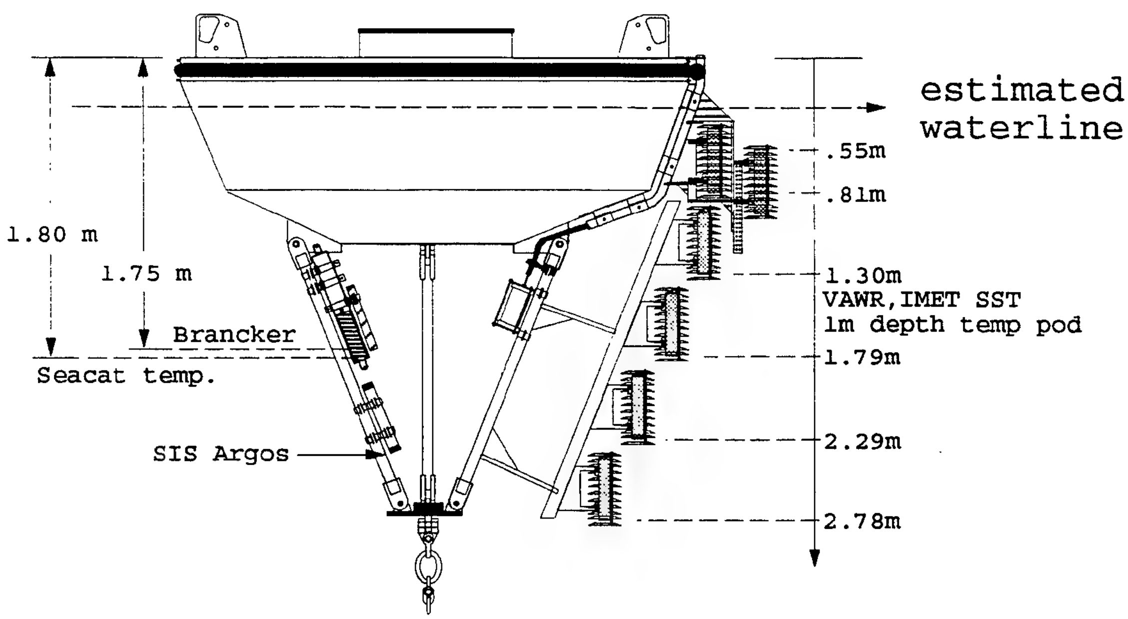
e. Brancker Temperature Recorders

A total of 18 Richard Brancker Research Ltd temperature data loggers (also known as "Branckers" or "T-Pods") were deployed at various depths from .25 meters to 300 meters on the WHOI surface mooring. Figure 4 (mooring schematic) lists the depths where T-Pods were located. The Brancker temperature loggers take a single point temperature measurement every record sample. The UOP Branckers were set for a record rate of 15 minutes.

Six Branckers were mounted on the buoy hull and bridle at depths ranging from .25 meters down to 2.5 meters. Figure 5 shows the discus buoy hull and the location of the six near surface T-pods. The near-surface temperature loggers are mounted in multi-plate solar radiation shields which are intended to minimize the direct solar heating of the instrument. The depths shown in Figure 5 are relative to the buoy deck. The instruments were positioned relative to a predicted waterline which was based on a prediction of the mooring tensions. The mean location of the waterline will be measured when the buoy is recovered. The actual depths of the sensors will then be computed. During a small boat visit to the buoy shortly after deployment the depth of the top Brancker was measured relative to the water surface and was very close to the desired .25 meters.

Two UOP Branckers were deployed on each of the University of Washington PCM moorings. Both moorings had one mounted on the top sphere at approximately 20 meters depth and the other was at 250 meters depth.

UOP Arabian Sea Discus
Bridle Configuration



Note:
measurements were made
from buoy deck down.
scale: 1"= 3'
W.Ostrom
11/4/94

Figure 5: Near-surface temperature array on the WHOI discus buoy.

f. Miniature Temperature Recorder (MTR)

A single Pacific Marine Environmental Lab, Miniature Temperature Recorder (MTR), was mounted at 3.5 meters depth in-line on the mooring. The MTR was mounted inside a 5-sided heavy duty steel box which was attached to an in line tension bar. Such a mounting arrangement was necessary to protect the MTR since its close proximity to the buoy bridle places it in a very vulnerable location during deployment and recovery. The MTR takes a single point temperature measurement every record sample which for the Arabian Sea deployment was set at 7.5 minutes.

g. WHOI Vector Measuring Current Meters

Five WHOI Vector Measuring Current Meters (VMCM) were deployed on the WHOI surface mooring at 5, 15, 25, 45, and 55 meters depth. The five surface mooring VMCMs record data on digital cassette every 3.75 minutes. A description of how each parameter is sampled is provided in Appendix 6.

The WHOI VMCMs incorporated several changes to the standard EG&G Sea Link product. These included different propeller bearings, a different plastic for the propeller blades and a redesign of the instrument cage including recent gussetting specifically for the Arabian Sea deployment. All VMCMs deployed on the WHOI surface mooring had cages with 3/4" cage rods and a single cross brace to support the sting between the two sets of propellers. See section 1A of this report for more details about the cage gussetting.

The VMCM's were outfitted with Silicone Nitride bearings, which have performed well in previous at-sea deployments. During the Subduction experiment VMCM propeller assemblies outfitted with similar bearings were deployed for a total of 24 months without any bearing failures. The propeller blades used in the Arabian Sea were made from injection molded Delrin® 100ST. Details about the VMCM bearings and propeller blade material can be found in Trask and Brink (1993).

Five WHOI VMCMs were also deployed on the University of Washington southern PCM mooring. Their nominal depths were 300, 500, 750, 1500, and 3000 meters. The record rate of the PCM mooring VMCMs was 7.5 minutes since a one year deployment was planned. Propeller shaft bearings and propeller materials were the same as those used on the WHOI surface mooring VMCMs. The VMCM cages used on the PCM mooring had 1/2" cage rods and a single cross brace to support the sting.

h. USC Multi-Variable Moored System

USC deployed two multivariable moored systems (MVMS) units on the WHOI surface mooring at 35 meters and 80 meters. Each MVMS records current vectors, rotor counts, compass, temperature, PAR, dissolved oxygen, dissolved oxygen

temperature, ~5 cm transmissometer, fluorometer, conductivity, and natural fluorescence (683 nm) at 3.75 minute time intervals set to GPS time and synchronized to the hour mark.

i. LDEO Multi-Variable Moored System

LDEO deployed two multivariable moored systems (MVMS) on the WHOI surface mooring at 10 meters and 65 meters. On the LDEO MVMS instruments conductivity, temperature, dissolved oxygen, transmissometer, 683, fluorescence and PAR sensors data were recorded every 4 minutes. Current measurements made by a VMCM were recorded every 7.5 minutes.

The manufacturers of the various MVMS sensors are listed below:

Sensor	Manufacturer
VMCM current sensor	EG&G
Conductivity	Sea bird
Temperature	Sea bird
Dissolved Oxygen	Endeco
Transmissometer	Sea Tech
683	Bio Spherical Instruments
Fluorometer	Sea Tech
PAR	Bio Spherical Instruments

j. Tracor Applied Sciences Bio-Acoustic Instrument

A Tracor Applied Sciences bio-acoustic transceiver array measuring backscattering at multiple frequencies to give zooplankton estimates by size distributions was deployed on the WHOI surface mooring at 40 meters. Backscattering at frequencies of 104, 165, 420, 700, 1100, 1850 and 3000 kHz are recorded each hour. Selected frequencies are also recorded on the half hour.

k. Acoustic Release

An acoustic release is used just above the anchor to release the mooring from the anchor. It is also used as transponder to precisely locate the anchor on the bottom. The type of release used on the WHOI discus mooring was an EG&G, Model 8202 BACS release.

Section 3: Cruise Chronology

R/V *Thomas Thompson* cruise number 40 departed Muscat, Oman, on 11 October 94 at 0300 UTC. The purpose of the cruise was to deploy five moorings as part of the Arabian Sea experiment.

While enroute to the mooring site T-7 XBTs were deployed hourly on the hour beginning at 1200 UTC on 11 October 1994. The hourly XBTs continued until 0200 UTC on 13 October 94. A CTD station at 16°00.09'N, 61°29.99'E was taken prior to beginning a detailed bathymetry survey of the mooring deployment area. The bathymetry data was collected by the ship's Hydrosweep system. In conjunction with the bathymetry survey, XBTs were taken every 15 minutes starting at 0539 UTC 13 October 1994. The XBT survey ended at 2114 UTC on 14 October 1994. Data were collected from a total of 202 XBTs. The XBT positions are listed in Appendix 2.

WHOI Central Surface Mooring

Deployment of the WHOI surface mooring began on Saturday 15 October 1994 at 0200 UTC. Since there was minimal wind the ship was positioned 6 miles up-current (east northeast) of the desired anchor site. With the ship dead in the water the upper 35 meters of the mooring was deployed on the port side beginning with the 35 meter USC MVMS and the 2.25 meter shot of 3/4" chain below it. The instrumentation and wire rope above 35 meters depth were then lowered into the water sequentially. The discus was then attached and deployed without any problems at 0243 UTC. The wire rope shot that had been outfitted with yale grips and used as a tag line during the deployment of upper instrumentation was then hauled back and removed. The 40 meter Tracor Applied Sciences bio-acoustic instrument was placed in line and the remaining instrumentation was deployed without incident. Details of the deck layout and the mooring deployment are found in Appendix 7.

The WHOI mooring was originally designed for a water depth of 3800 meters. The actual water depth turned out to be 4032 meters which meant that an additional 232 meters of 7/8" nylon had to be added to the mooring. The 100 meter adjustable shot called for in the original mooring design was therefore replaced with a 332 meter shot.

The mooring was towed for about 25 minutes after all the synthetics had been deployed. The glass balls were then placed in line along with the acoustic release, anchor pendant and chain, and again rigged for towing. The mooring was towed for two hours while the ship moved into position for anchor drop. At 1048 UTC the anchor was deployed.

Following the anchor launch the ship was repositioned to watch the discus buoy settle out. A slight wake behind the buoy was initially observed along with

minimal free board. As the wake subsided the free board increased to a more normal level.

An acoustic release/anchor survey was then conducted once the buoy appeared to have settled out. The water depth at the site was 4032 meters corrected (4017 depth recorder reading plus 15 meter Matthew's correction). Based on depth recorder errors discovered later in the trip the actual water depth may be approximately 20 meters less. A sound speed of 1506 meters per second was used during the acoustic release survey (Figure 6). The GPS anchor position was determined to be 15°30.04'N latitude and 61°29.99'E longitude. Based on the anchor drop position the anchor fell back approximately 300 meters or 7.5% of the water depth.

Following the acoustic release survey four CTD stations were taken. Figure 7 shows the CTD cast taken near the WHOI surface mooring approximately three hours after it was deployed. The positions of all the CTD stations made during the cruise can be found in Appendix 3.

SIO Northern Surface Mooring

The second mooring to be deployed was an SIO surface mooring which took place on 16 October 1994. Each SIO surface mooring had two suites of meteorological sensors measuring wind speed and direction, barometric pressure, air temperature, short wave radiation and sea surface temperature. Housed in the bridle of the toroid buoy was a downward looking acoustic doppler current profiler. Additional subsurface instrumentation included ten temperature recorders attached to the upper shot of wire. Figure 8 is a schematic of the SIO surface mooring. Both SIO moorings deployed during TN040 were identical.

The first SIO surface mooring deployment appeared to go smoothly. While conducting a survey of the acoustic release following the deployment the ship's bridge sighted a cluster of glass balls on the surface. The small boat with two crew members and Will Ostrom (WHOI) and Dan Rudnick (SIO) was launched to investigate. The small boat attached a tow line to the glass ball cluster and began to tow the glass balls to the ship. As the small boat approached the stern of the ship the tag line attached to the glass balls was transferred to the ship. A decision was made to recover the glass ball cluster and try to determine the cause of the failure. The deck was rigged for recovery and the glass balls were brought aboard.

The bottom end of the recovered glass balls had a 3/4" shackle which indicated that a link of chain had failed. The pin of the 3/4" shackle had been in the top link of the 1/2" chain on the last string of four glass balls above the release. In preparation for the cruise SIO had pre-attached hardware to the ends of the glass ball chain. In so doing it had forced 3/4" shackle pins through the end links of their 1/2" glass ball chain. The shackle pins were so tight that they could not be removed to attach

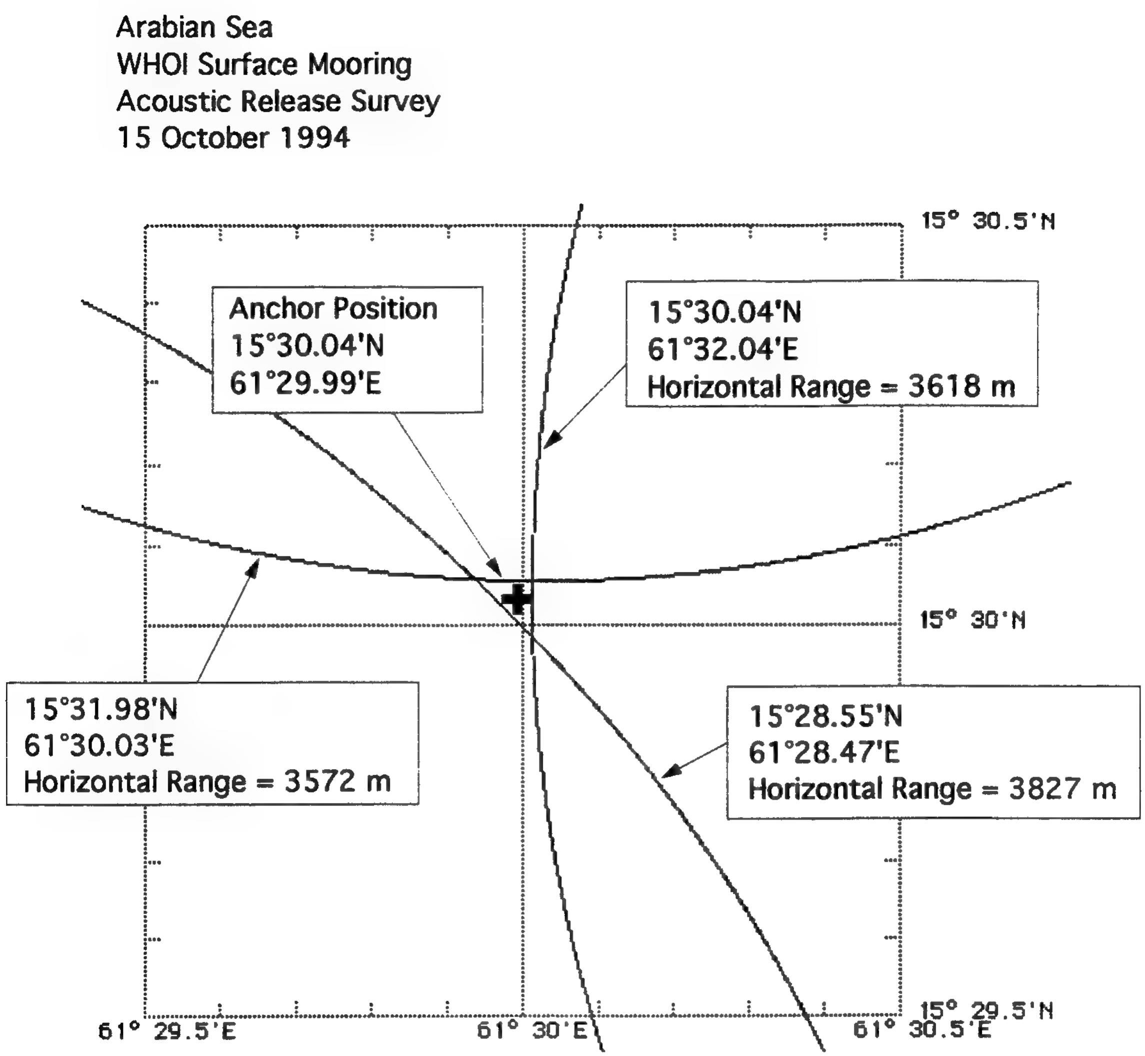


Figure 6: WHOI surface mooring acoustic release survey.

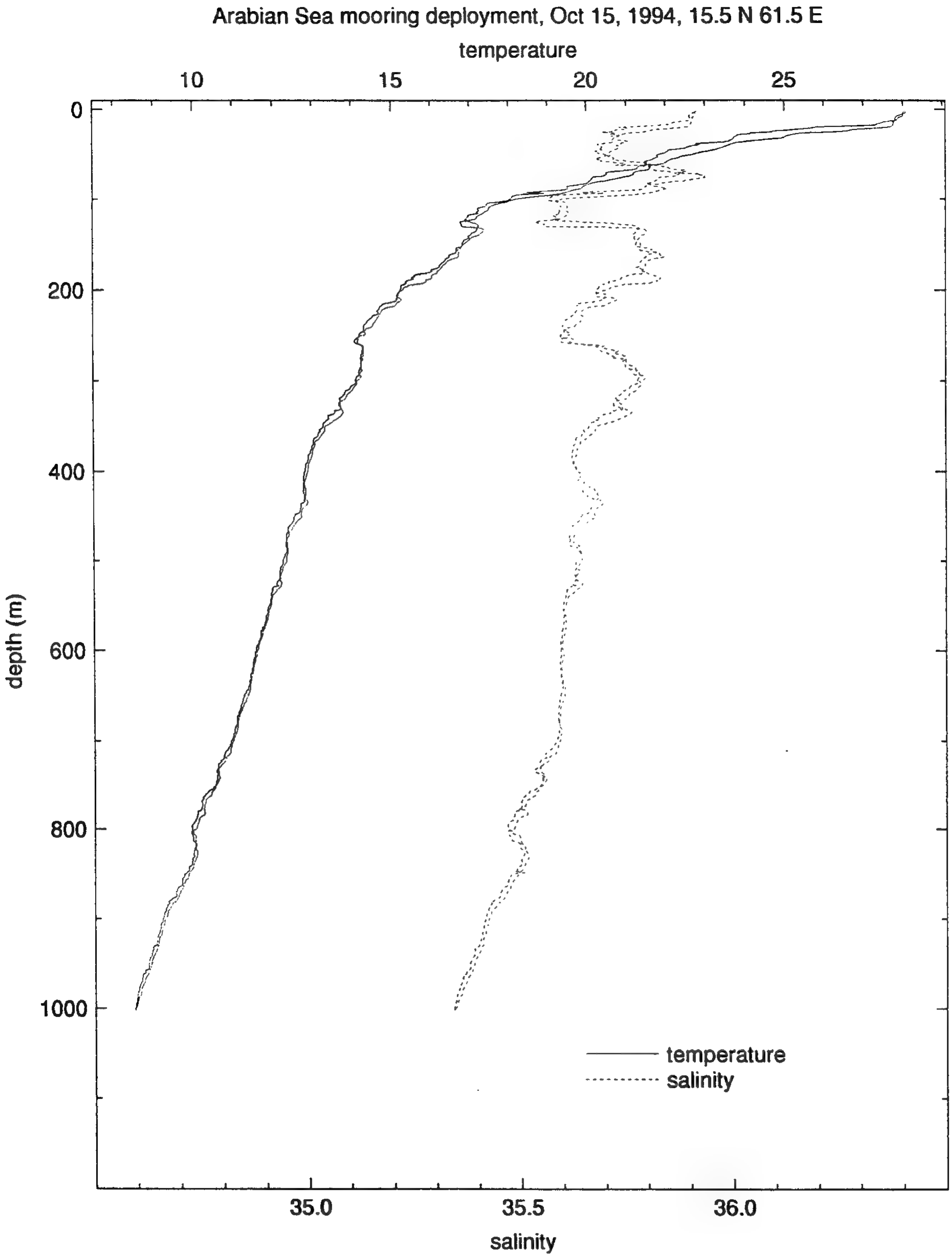


Figure 7: Profile of CTD data collected near the WHOI surface mooring.

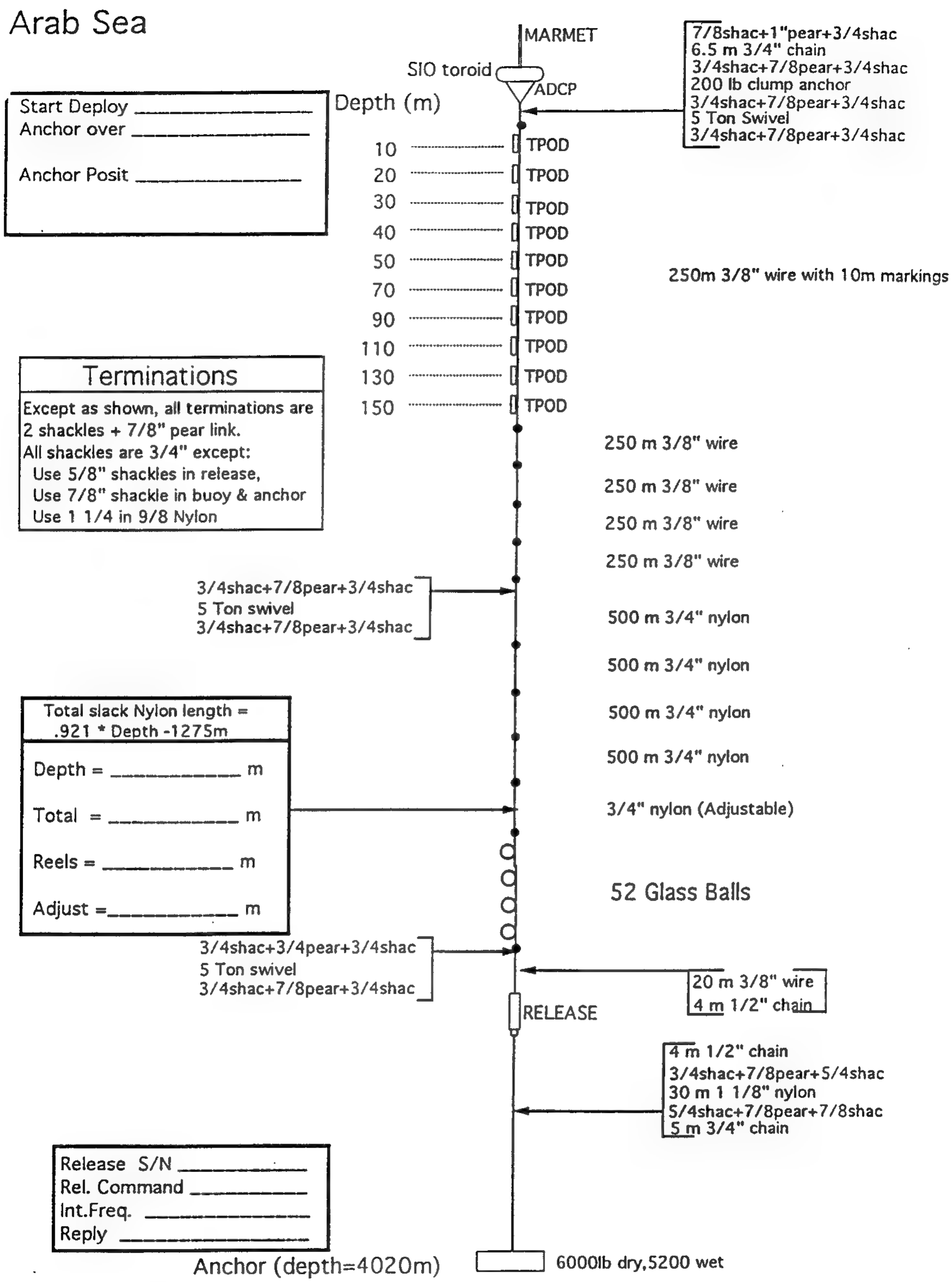


Figure 8: SIO surface mooring schematic.

adjacent strings. Rather than try to force them out during deployment an additional shackle was dipped through the existing shackle. The failure had occurred in a link of chain that had the 3/4" shackle pin forced through it. It appears that damage may have occurred to the 1/2" chain when forcing the 3/4" shackle pins through the chain.

Since there may have been other damaged links the end links with 3/4" shackles were removed from all the remaining glass balls strings with chain cutters. Rather than use 3/4" shackles again it was decided to use 5/8" shackles that would easily fit the 1/2" chain.

The remainder of the SIO mooring was recovered up to the first 250 meter shot of 3/8" wire which contained the ten temperature recorders. All recovered components appeared in good condition. It was felt that there was significant potential for damaging the buoy and meteorological sensors if the buoy were recovered so it was decided to leave the buoy in the water and tow it to the deployment start position. During the tow the mooring crew rested.

Redeployment began at 0100 UTC on 17 October 1994. Prior to redeployment the 250 meter shot of wire was hauled in up to the 40 meter temperature recorder to inspect the wire. All appeared in good condition. The mooring was paid out and all instrumentation was returned to its original depths. The deployment continued and the anchor was deployed without any problems. Details of the SIO anchor deployment scheme can be found in Appendix 7.

While the ship was deploying the SIO mooring for the second time the acoustic release from the first deployment which was still on the bottom with one string of four glass balls was fired. Once it was sited on the surface the small boat was launched with Jim Dufour (SIO) and Neil Bogue (UW) who with the help of the crew recovered the equipment.

An acoustic release survey of the second setting followed the anchor deployment. The GPS anchor position of the northernmost SIO mooring was determined to be 15°43.53'N, 61°15.94'E.

Following the acoustic release survey of the SIO surface mooring the ship moved to the WHOI discus buoy site where the small boat was launched so that the discus buoy could be inspected. Will Ostrom and Rick Trask boarded the buoy and visually inspected the meteorological instrumentation. Photographs were taken of the sub-surface instrumentation and the depth of the upper instrument on the near-surface temperature string was checked. Everything seemed operational and in order.

SIO Southern Surface Mooring

The second SIO surface mooring was deployed on 18 October 1994. To prevent the same occurrence of chain failure that the first SIO mooring experienced the ends of the glass ball chain that had 3/4" shackles forced in the 1/2" chain were removed. The chain shots were interconnected with 5/8" shackles and pear rings. The deployment proceeded without any problems. An acoustic release survey followed the anchor deployment. The GPS anchor position for the southern SIO surface mooring was determined to be 15°16.53'N, and 61°16.11'E.

UW PCM Mooring Deployments

The first UW PCM mooring deployment began on the morning of 19 October 1994. The southern PCM mooring was set first. The deployment went relatively smoothly. This particular PCM mooring had five WHOI VMCMs at 300, 500, 750, 1500 and 3000 meters depth. In addition a Brancker temperature recorder was placed on the top sphere at 20 meters depth and a second was placed at 250 meters. Appendix 8 contains deployment details about the WHOI instrumentation deployed on the PCM moorings. Great care was taken during the deployment to make sure the mooring length was adjusted precisely for the water depth since the top sphere of the PCM mooring is designed to be close to the surface. An acoustic release survey followed the mooring deployment. The GPS anchor position for the southern PCM mooring was determined to be 15°16.37'N, 61°44.07'E.

After the anchor deployment five CTD stations were made down to 1000 meters depth. The start times and positions of those stations can be found in Appendix 3.

The northernmost PCM mooring deployment began in the morning of 20 October 1994. The ship was positioned down-wind of the anchor site since there was little current detected. The top sphere and PCM were deployed without any problem. While paying out the PCM guide wire it became apparent that a current had developed in the same direction the ship was headed. Since we did not want to go very fast over the bottom so as not to over-shoot the target the ship's speed through the water was very slow which in turn dictated the mooring payout rate. Since we were paying the mooring out very slowly and the ship was moving toward the target too quickly it was decided to recover the mooring and reposition the ship down-current of the anchor site. In addition the PCM was reinitialized so that there would be sufficient time to get the mooring in the water before it attempted to make its first profile. This pushed the start of the deployment back to approximately 0500 UTC.

The ship was repositioned only to find out that the current had again changed which required a different start position. The ship was repositioned and the deployment was started. For some unknown reason the current was again with the ship and payout rates had to be kept low. Concern that the ship would over-shoot the target position

prompted the deployment of the small boat so that it could be used to pull the mooring away from the ship. Once the small boat started pulling, the deployment proceeded quite smoothly. The small boat stayed in the vicinity of the top of the mooring while the anchor was deployed. An acoustic release survey that followed the deployment placed the anchor at 15°43.75'N, 61°43.95'E. This however was not the final resting place of the northern PCM mooring.

The northern PCM mooring had a WHOI Brancker temperature recorder on the top sphere at 20 meters depth and a second was placed at 250 meters. This mooring also had a Tracor Applied Sciences bio-acoustic instrument at 215 meters depth.

The following day (21 October 94) was spent taking a number of CTD stations. At 0300 UTC the ship was positioned in the vicinity of the WHOI discus buoy. A 1000 meter deep CTD station was taken before beginning a four hour period of intense meteorological observations at the buoy. During the meteorological observations the ship was positioned up wind of the buoy so that the VAWR Argos transmissions could be received and logged.

After leaving the discus buoy site more CTD stations were taken. The CTD was later attached to the conducting cable and led through the stern A-frame. The CTD was tow yoed from the southern PCM site northward beginning with station 26-1. During the tow yos the CTD was cycled between the surface and 300 meters depth. The last tow yo station (26-35) was taken at 0124 UTC on 22 October 94 at position 15°43.51'N, 61°44.65'E. Once the CTD was aboard the ship got underway for Muscat, Oman.

Following the deployment of the northern PCM mooring several reports had been received from Draper Labs that an ARGOS transmission had been received from the ARGOS transmitter on top of the northern PCM mooring. No position information could be ascertained from the occasional reception. These reports were a concern but stray transmissions have on occasion been received in the past with nothing ever coming of it. Another report came in on the morning of 22 October 94 but this time position information was included. The position was within a quarter mile of the northern PCM anchor position.

The chief scientist decided to turn the ship around and head back toward the northern PCM mooring site fearing that the top sphere must be coming out of the water occasionally permitting the Argos transmissions to get through. An extra day of ship time was approved so that the mooring could be recovered and reset.

Upon arriving at the site the top sphere was in fact sited going in and out of the water. The mooring recovery procedure was debated at great length. The final decision was to deploy the small boat and have them hook into the top sphere and tow the mooring away after the bottom release was fired. The plan was to recover the bottom of the mooring up to the 60" syntactic foam sphere, leaving the PCM in the water so as

not to damage it or the guide wire. The weather was deteriorating. Squalls were passing through with rain showers and high winds. The captain ordered the small boat to release the top sphere and to move away from the mooring when the release was fired. After the release was fired the small boat could go back and get the top sphere in tow. Following the release firing the 60" sphere came up very close to the smaller top sphere and in so doing there was concern that the PCM guide wire and the top shot of mooring wire might be fouled. The delay in towing immediately after the release had been fired increased the risk of fouling the top part of the mooring.

Since the plan to stretch the mooring out on the surface did not work the upper release was then fired to separate the top of the mooring from the large sphere. The small boat then began towing the top of the mooring toward the ship. During the tow the large sphere stayed in close proximity to the top of the mooring. This confirmed that the top and bottom had become fouled in some manner.

The small boat transferred the tow line to the ship and stood by while the upper sphere was brought on board. The captain then had the small boat recovered because of approaching squalls. The PCM and large sphere were recovered. The PCM guide wire was damaged but fortunately the PCM was still in good condition. The remainder of the mooring recovery proceeded without any major problems. Throughout the latter part of the recovery the wind was blowing 30–40 knots and seas had built to 10 to 15 feet. Following the recovery everyone rested for several hours with the hope of trying to reset the mooring starting at 2000 UTC.

The reason why the mooring ended up in water shallower than expected was unclear. Great care had been taken to do a good bathymetric survey of the site and all shots of wire had been carefully measured with a laser during fabrication. The cause of the error was unknown. Additional bathymetry data were collected while recovering the mooring and while preparing to redeploy. Duplicate readings from two depth recorders revealed a 15 meter discrepancy. The original depth recorder was keying on the middle of the return signal rather than the leading edge. As a result there was a 12 millisecond difference between the two. Once the original recorder was adjusted to key on the leading edge the two units agreed.

The mooring crew reconvened at 2000 UTC but weather conditions were too marginal to start the deployment. Everyone was told to stand down until 0100 UTC of 23 October 94 at which time a decision would be made as to whether a deployment would be attempted.

At 0100 UTC the weather had not improved a great deal but a decision was made to attempt the deployment. The PCM and upper sphere were deployed as a unit so as to get the sphere away from the stern of the ship quickly. The guide wire was paid out and the 60" syntactic sphere was deployed without incident. The details of the PCM and sphere deployment can be found in Appendix 7. As the deployment proceeded the weather was slowly improving. The anchor was deployed and an

acoustic release survey followed. The GPS anchor position was determined to be 15°43.90'N, 61°44.53'E. At approximately 1000 UTC the ship once again got underway for Muscat, Oman.

The depth recorder error has more than likely plagued the southern PCM mooring as well. When the southern mooring was set there was a considerable current flowing in the southern part of the array which would tend to keep the PCM below the surface due to mooring inclination. If the current subsides Argos transmissions may be received from the southern mooring as well. During TN040 there was no additional ship time or spare mooring components left to do recovery/redeployment at the southern site. The depth recorder error should have little impact on the WHOI and SIO surface moorings since they are more tolerant of depth uncertainties.

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Trask, Richard P. and Nancy J. Brink, 1993: The Subduction Experiment. Cruise Report: R/V Oceanus Cruise Number 240 Leg 3, Subduction 1 mooring ployment cruise, 17 June - 5 July 1991, Upper Ocean Processes Group, UOP Technical Report 93-1, Woods Hole Oceanographic Institution Technical Report, WHOI-93-12, 77 pages.

Acknowledgements

The authors wish to thank the captain and crew of the R/V *Thomas Thompson* for all their efforts to make the deployment cruise a success. Special thanks go to the mooring deployment crew, Neil Bogue, Jim Dufour, Lloyd Regier, Chris Kinkade, Bob Weller and Dan Rudnick who put in some early mornings, hot days and late nights to get the job done.

The WHOI mooring was designed by George Tupper and carefully prepared by the WHOI rigging shop under the direction of David Simoneau. We sincerely thank Nancy Brink and Mary Ann Lucas for their help in preparing this report.

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Appendix 1

Cruise Participants

Charles Eriksen	University of Washington	Chief Scientist
Robert Weller	Woods Hole Oceanographic Institution	
Daniel Rudnick	Scripps Institution of Oceanography	
Neil Bogue	University of Washington	
Jack Shillingford	Charles Stark Draper Labs	
Jim Dufour	Scripps Institution of Oceanography	
Lloyd Regier	Scripps Institution of Oceanography	
Matt Trunnel	Scripps Institution of Oceanography	
William Ostrom	Woods Hole Oceanographic Institution	
Bryan Way	Woods Hole Oceanographic Institution	
Geoff Allsup	Woods Hole Oceanographic Institution	
Rick Trask	Woods Hole Oceanographic Institution	
Derek Manov	University of Southern California	
Malgorzata Stramska	University of Southern California	
Marcella Stern	Lamont Doherty Earth Observatory	
Miguel Maccio	Lamont Doherty Earth Observatory	
Michelle Valenti	University of South Florida	
Danielle Bartolacci	University of South Florida	
Chris Kinkade	Lamont Doherty Earth Observatory	
Guy Rosinbaum	Texas A and M University	
Joel Seymour	Texas A and M University	
Dale Ripley	University of Washington	
Mike Realander	University of Washington	

Appendix 2

Appendix 2. XBT Positions and Times from R/V Thompson 40

NO.	GMT TIME	GMT DATE	LATITUDE	LONGITUDE	BUCKET TEMPERATURE
1	12:14:00	10/11/94	22 19.472 N	60 00.405 E	T = 27.25C
3	13:57:49	10/11/94	21 58.463 N	60 05.890 E	T = 27.4 C
4	14:56:41	10/11/94	21 46.310 N	60 08.610 E	T = 27.6 C
5	16:10:52	10/11/94	21 32.334 N	60 11.545 E	T = 27.3 C
6	16:56:13	10/11/94	21 23.303 N	60 13.192 E	T = 27.6 C
7	17:59:52	10/11/94	21 09.758 N	60 15.689 E	T = 27.5 C
8	18:56:26	10/11/94	20 58.036 N	60 19.062 E	T = 27.2 C
9	19:58:19	10/11/94	20 45.317 N	60 22.732 E	T = 26.7 C
10	20:58:16	10/11/94	20 33.277 N	60 26.201 E	T = 26.8 C
11	21:57:40	10/11/94	20 21.443 N	60 30.483 E	T = 26.8 C
12	23:02:13	10/11/94	20 09.975 N	60 32.542 E	T = 27.0 C
13	23:57:00	10/11/94	19 58.898 N	60 34.650 E	T = 27.1 C
14	0:55:00	10/12/94	19 46.826 N	60 36.417 E	T = 27.5 C
15	1:57:00	10/12/94	19 34.312 N	60 39.300 E	T = 27.5 C
16	2:57:00	10/12/94	19 21.567 N	60 42.517 E	T = 27.3 C
17	3:56:13	10/12/94	19 09.134 N	60 45.785 E	T = 27.5 C
18	4:56:59	10/12/94	18 56.537 N	60 48.499 E	T = 27.3 C
19	5:55:44	10/12/94	18 45.590 N	60 51.048 E	T = 27.2 C
20	6:54:28	10/12/94	18 33.730 N	60 54.324 E	T = 27.9 C
21	7:01:43	10/12/94	18 32.259 N	60 54.779 E	T = 27.9 C
22	7:55:36	10/12/94	18 20.970 N	60 57.968 E	T = 28.0 C
24	8:06:53	10/12/94	18 18.560 N	60 98.660 E	T = 28.5 C
25	8:50:34	10/12/94	18 09.199 N	61 00.837 E	T = 28.5 C
26	16:57:07	10/12/94	17 57.439 N	61 08.288 E	T = 27.7 C
27	17:55:36	10/12/94	17 44.550 N	61 05.450 E	T = 27.4 C
28	18:55:21	10/12/94	17 31.664 N	61 07.924 E	T = 27.3 C
29	19:57:37	10/12/94	17 19.377 N	61 10.436 E	T = 26.8 C
30	20:56:08	10/12/94	17 06.664 N	61 13.200 E	T = 27.4 C
31	21:54:16	10/12/94	16 54.422 N	61 16.209 E	T = 26.9 C
32	23:00:21	10/12/94	16 40.422 N	61 19.790 E	T = 27.4 C
33	23:55:00	10/12/94	16 29.029 N	61 22.531 E	T = 27.5 C
34	0:58:30	10/13/94	16 16.793 N	61 25.340 E	T = 27.5 C
35	1:59:00	10/13/94	16 04.075 N	61 28.810 E	T = 28.0 C
36	5:39:18	10/13/94	16 00.485 N	61 29.576 E	T = 28.5 C
37	6:12:07	10/13/94	16 00.485 N	61 29.576 E	T = 28.6 C
38	6:26:00	10/13/94	15 54.968 N	61 32.128 E	T = 28.6 C
39	6:40:03	10/13/94	15 53.044 N	61 34.075 E	T = 25.5 C
40	6:44:29	10/13/94	15 52.410 N	61 34.795 E	T = 28.5 C
41	6:56:26	10/13/94	15 50.719 N	61 36.531 E	T = 28.7 C
42	7:06:43	10/13/94	15 49.996 N	61 37.326 E	T = 28.7 C
43	7:12:41	10/13/94	15 48.393 N	61 38.994 E	T = 28.4 C
44	7:26:09	10/13/94	15 46.469 N	61 40.936 E	T = 28.5 C
45	7:43:38	10/13/94	15 43.970 N	61 43.540 E	T = 28.5 C
46	7:55:36	10/13/94	15 42.270 N	61 45.320 E	T = 28.4 C
47	8:10:51	10/13/94	15 40.054 N	61 47.570 E	T = 28.7 C
48	8:18:07	10/13/94	15 38.961 N	61 48.086 E	T = 28.7 C
49	8:27:32	10/13/94	15 37.596 N	61 50.117 E	T = 28.6 C
50	8:45:22	10/13/94	15 34.993 N	61 52.838 E	T = 28.5 C

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NO.	GMT TIME	GMT DATE	LATITUDE	LONGITUDE	BUCKET TEMPERATURE
51	8:58:49	10/13/94	15 33.063 N	61 54.854 E	T = 28.6 C
52	9:10:45	10/13/94	15 31.280 N	61 56.640 E	T = 28.8 C
53	9:26:32	10/13/94	15 28.920 N	61 56.860 E	T = 28.9 C
54	9:42:09	10/13/94	15 26.730 N	61 54.590 E	T = 28.8 C
55	9:56:29	10/13/94	15 24.680 N	61 52.510 E	T = 28.8 C
56	10:11:33	10/13/94	15 22.530 N	61 50.240 E	T = 28.9 C
57	10:26:49	10/13/94	15 20.345 N	61 47.987 E	T = 28.4 C
58	10:42:39	10/13/94	15 18.081 N	61 45.617 E	T = 28.5 C
59	10:57:25	10/13/94	15 15.963 N	61 43.451 E	T = 28.4 C
60	11:12:13	10/13/94	15 13.890 N	61 41.280 E	T = 28.4 C
61	11:27:29	10/13/94	15 11.770 N	61 34.110 E	T = 28.3 C
62	11:40:00	10/13/94	15 09.900 N	61 31.150 E	T = 28.4 C
63	11:59:00	10/13/94	15 07.446 N	61 34.620 E	T = 28.6 C
64	12:15:06	10/13/94	15 05.328 N	61 32.432 E	T = 28.7 C
65	12:28:45	10/13/94	15 03.363 N	61 30.400 E	T = 28.6 C
66	12:42:17	10/13/94	15 04.398 N	61 28.575 E	T = 28.5 C
67	12:57:03	10/13/94	15 06.611 N	61 26.287 E	T = 28.5 C
68	13:13:10	10/13/94	15 08.531 N	61 24.273 E	T = 28.4 C
69	13:26:40	10/13/94	15 10.326 N	61 22.370 E	T = 28.4 C
70	13:44:10	10/13/94	15 12.734 N	61 19.921 E	T = 28.4 C
71	13:59:11	10/13/94	15 14.801 N	61 17.796 E	T = 28.3 C
72	14:16:25	10/13/94	15 17.151 N	61 15.335 E	T = 28.4 C
73	14:31:31	10/13/94	15 19.251 N	61 13.119 E	T = 28.0 C
74	14:44:56	10/13/94	15 21.149 N	61 11.156 E	T = 28.1 C
75	14:58:36	10/13/94	15 23.066 N	61 09.192 E	T = 28.0 C
76	15:03:57	10/13/94	15 23.836 N	61 08.384 E	T = 28.0 C
77	15:14:45	10/13/94	15 25.839 N	61 06.830 E	T = 28.0 C
78	15:29:53	10/13/94	15 27.480 N	61 04.630 E	T = 28.1 C
79	15:44:35	10/13/94	15 29.581 N	61 02.422 E	T = 28.2 C
80	15:56:27	10/13/94	15 31.344 N	61 03.458 E	T = 28.0 C
81	16:13:01	10/13/94	15 34.068 N	61 06.243 E	T = 27.8 C
82	16:28:06	10/13/94	15 36.519 N	61 08.780 E	T = 28.1 C
83	16:41:33	10/13/94	15 38.713 N	61 10.959 E	T = 28.0 C
84	16:54:57	10/13/94	15 40.876 N	61 13.229 E	T = 28.1 C
85	17:13:01	10/13/94	15 43.786 N	61 16.276 E	T = 28.0 C
86	17:26:54	10/13/94	15 45.990 N	61 18.523 E	T = 27.9 C
87	17:41:40	10/13/94	15 48.295 N	61 20.981 E	T = 27.9 C
88	17:56:07	10/13/94	15 50.523 N	61 23.339 E	T = 28.0 C
89	18:11:20	10/13/94	15 52.876 N	61 25.658 E	T = 27.8 C
90	18:26:53	10/13/94	15 54.401 N	61 28.144 E	T = 28.1 C
91	18:43:29	10/13/94	15 51.819 N	61 30.717 E	T = 28.1 C
92	18:58:06	10/13/94	15 49.596 N	61 33.075 E	T = 28.0 C
93	19:12:25	10/13/94	15 47.447 N	61 35.345 E	T = 28.0 C
94	19:27:19	10/13/94	15 45.144 N	61 37.698 E	T = 27.9 C
95	19:41:36	10/13/94	15 43.021 N	61 39.922 E	T = 27.6 C
96	19:55:03	10/13/94	15 40.994 N	61 41.972 E	T = 27.5 C

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NO.	GMT TIME	GMT DATE	LATITUDE	LONGITUDE	BUCKET TEMPERATURE
97	20:11:56	10/13/94	15 38.426 N	61 44.612 E	T = 27.9 C
98	20:28:49	10/13/94	15 35.847 N	61 47.291 E	T = 28.1 C
99	20:43:38	10/13/94	15 33.572 N	61 49.635 E	T = 27.9 C
100	20:57:52	10/13/94	15 31.430 N	61 51.845 E	T = 27.6 C
101	21:14:15	10/13/94	15 28.963 N	61 52.259 E	T = 27.9 C
102	21:28:07	10/13/94	15 27.042 N	61 50.209 E	T = 27.8 C
103	21:43:58	10/13/94	15 24.777 N	61 47.939 E	T = 27.6 C
104	21:59:03	10/13/94	15 22.667 N	61 45.696 E	T = 26.5 C
105	22:14:27	10/13/94	15 20.466 N	61 43.451 E	T = 27.6 C
106	22:28:21	10/13/94	15 18.491 N	61 41.446 E	T = 27.6 C
107	22:44:46	10/13/94	15 16.246 N	61 39.052 E	T = 27.5 C
108	22:59:28	10/13/94	15 14.142 N	61 36.946 E	T = 27.4 C
109	23:15:13	10/13/94	15 12.008 N	61 34.657 E	T = 27.8 C
110	23:29:04	10/13/94	15 10.039 N	61 32.689 E	T = 27.8 C
111	23:45:00	10/13/94	15 07.870 N	61 30.440 E	T = 27.8 C
112	0:00:00	10/14/94	15 09.014 N	61 28.500 E	T = 28.0 C
113	0:15:00	10/14/94	15 11.221 N	61 26.184 E	T = 27.8 C
114	0:28:00	10/14/94	15 12.903 N	61 24.448 E	T = 27.8 C
115	0:43:50	10/14/94	15 15.134 N	61 22.049 E	T = 27.6 C
116	0:58:00	10/14/94	15 17.156 N	61 19.988 E	T = 27.0 C
117	1:13:15	10/14/94	15 19.334 N	61 17.703 E	T = 27.0 C
118	1:27:33	10/14/94	15 21.420 N	61 15.512 E	T = 27.1 C
119	1:43:00	10/14/94	15 23.649 N	61 13.250 E	T = 27.1 C
120	1:59:00	10/14/94	15 25.698 N	61 11.126 E	T = 27.5 C
121	2:15:00	10/14/94	15 28.028 N	61 08.684 E	T = 27.6 C
122	2:29:00	10/14/94	15 30.143 N	61 06.689 E	T = 27.5 C
123	2:44:00	10/14/94	15 32.553 N	61 09.351 E	T = 27.7 C
124	2:58:00	10/14/94	15 34.775 N	61 11.538 E	T = 27.5 C
125	3:13:00	10/14/94	15 37.008 N	61 13.857 E	T = 27.6 C
126	3:27:51	10/14/94	15 39.144 N	61 16.198 E	T = 27.3 C
127	3:44:00	10/14/94	15 41.571 N	61 18.652 E	T = 27.7 C
128	3:56:17	10/14/94	15 43.358 N	61 20.448 E	T = 27.9 C
129	4:12:42	10/14/94	15 45.735 N	61 23.015 E	T = 27.8 C
130	4:28:08	10/14/94	15 47.962 N	61 25.294 E	T = 27.7 C
131	4:42:24	10/14/94	15 50.072 N	61 27.423 E	T = 27.8 C
132	4:55:46	10/14/94	15 48.501 N	61 29.548 E	T = 27.7 C
133	5:12:13	10/14/94	15 46.065 N	61 32.064 E	T = 27.7 C
134	5:25:55	10/14/94	15 44.067 N	61 34.074 E	T = 27.5 C
135	5:43:05	10/14/94	15 41.667 N	61 36.643 E	T = 27.6 C
136	5:57:12	10/14/94	15 35.645 N	61 38.713 E	T = 27.3 C
137	6:11:44	10/14/94	15 37.558 N	61 40.813 E	T = 27.5 C
138	6:28:12	10/14/94	15 35.182 N	61 43.268 E	T = 27.5 C
139	6:43:10	10/14/94	15 33.003 N	61 45.620 E	T = 27.7 C
140	6:59:33	10/14/94	15 30.458 N	61 48.233 E	T = 27.5 C
141	7:12:25	10/14/94	15 28.712 N	61 47.362 E	T = 27.7 C
142	7:27:35	10/14/94	15 26.554 N	61 45.129 E	T = 27.5 C
143	7:42:12	10/14/94	15 24.480 N	61 42.967 E	T = 27.6 C
144	8:09	10/14/94	15 20.41 N	61 38.723 E	T = 27.8 C
145	8:16:14	10/14/94	15 19.605 N	61 37.873 E	T = 27.8 C

NO.	GMT TIME	GMT DATE	LATITUDE	LONGITUDE	BUCKET TEMPERATURE
146	8:29:00	10/14/94	15 17.740 N	61 35.950 E	T = 29.9 C
147	8:42:30	10/14/94	15 15.894 N	61 34.034 E	T = 27.8 C
148	8:58:48	10/14/94	15 13.640 N	61 31.730 E	T = 27.7 C
149	9:14:22	10/14/94	15 12.390 N	61 29.490 E	T = 27.8 C
150	9:29:30	10/14/94	15 16.580 N	61.27 380 E	T = 28.0 C
151	9:43:08	10/14/94	15 16.508 N	61 25.346 E	T = 28.0 C
152	9:57:26	10/14/94	15 18.504 N	61 23.254 E	T = 28.1 C
153	10:14:43	10/14/94	15 20.944 N	61 20.763 E	T = 28.1 C
154	10:28:34	10/14/94	15 22.917 N	61 18.692 E	T = 28.2 C
155	10:44:41	10/14/94	15 25.220 N	61 16.281 E	T = 28.2 C
156	10:58:48	10/14/94	15 27.290 N	61 14.120 E	T = 28.4 C
157	11:13:48	10/14/94	15 29.510 N	61 11.870 E	T = 28.4 C
158	11:27:28	10/14/94	15 30.120 N	61 13.880 E	T = 28.2 C
159	11:43:38	10/14/94	15 30.020 N	61 17.320 E	T = 28.4 C
160	11:58:39	10/14/94	15 30.033 N	61 20.601 E	T = 28.6 C
161	12:14:27	10/14/94	15 30.015 N	61 24.135 E	T = 28.6 C
162	12:29:52	10/14/94	15 30.045 N	61 27.600 E	T = 28.5 C
163	12:44:21	10/14/94	15 30.026 N	61 30.865 E	T = 28.5 C
164	12:59:52	10/14/94	15 30.007 N	61 34.245 E	T = 28.6 C
165	13:14:10	10/14/94	15 30.017 N	61 37.267 E	T = 28.6 C
166	13:28:36	10/14/94	15 30.000 N	61 40.546 E	T = 28.5 C
167	13:43:47	10/14/94	15 29.508 N	61 43.396 E	T = 28.4 C
168	13:58:21	10/14/94	15 27.430 N	61 41.302 E	T = 28.3 C
169	14:14:46	10/14/94	15 25.092 N	61 38.936 E	T = 28.0 C
170	14:29:48	10/14/94	15 22.982 N	61 36.723 E	T = 28.0 C
171	14:44:11	10/14/94	15 20.941 N	61 34.593 E	T = 28.0 C
172	15:00:57	10/14/94	15 10.519 N	61 32.154 E	T = 28.0 C
173	15:14:04	10/14/94	15 16.735 N	61 30.205 E	T = 28.0 C
174	15:28:01	10/14/94	15 18.410 N	61 28.067 E	T = 28.0 C
175	15:44:04	10/14/94	15 20.670 N	61 25.726 E	T = 27.4 C
176	15:54:45	10/14/94	15 22.177 N	61 24.127 E	T = 27.9 C
177	16:12:20	10/14/94	15 24.667 N	61 21.546 E	T = 27.8 C
178	16:27:59	10/14/94	15.26.929 N	61 19.159 E	T = 27.8 C
179	16:42:42	10/14/94	15 29.065 N	61 17.006 E	T = 27.4 C
180	16:57:04	10/14/94	15 31.169 N	61 14.789 E	T = 27.4 C
181	17:11:15	10/14/94	15 33.397 N	61 14.904 E	T = 27.6 C
182	17:42:36	10/14/94	15 38.342 N	61 19.950 E	T = 27.5 C
183	17:56:26	10/14/94	15 40.420 N	61 22.131 E	T = 27.5 C
184	18:12:21	10/14/94	15 42.807 N	61 24.625 E	T = 27.5 C
185	18:27:30	10/14/94	15 45.102 N	61 26.909 E	T = 27.6 C
186	18:42:00	10/14/94	15 44.332 N	61 29.190 E	T = 28.0 C
187	19:12:09	10/14/94	15 39.883 N	61 33.770 E	T = 27.8 C
188	19:26:57	10/14/94	15 37.663 N	61 36.048 E	T = 27.6 C
189	19:42:08	10/14/94	15 35.400 N	61 38.443 E	T = 27.5 C
190	19:57:52	10/14/94	15 33.037 N	61 40.886 E	T = 27.9 C
191	20:14:10	10/14/94	15 30.590 N	61 39.980 E	T = 28.0 C
192	20:27:48	10/14/94	15 28.665 N	61 37.964 E	T = 27.8 C
193	20:43:29	10/14/94	15 26.499 N	61 35.894 E	T = 27.8 C
194	20:56:37	10/14/94	15 24.631 N	61 33.790 E	T = 27.6 C
195	21:14:07	10/14/94	15 22.202 N	61 31.267 E	T = 27.8 C

Appendix 3

CTD Stations taken during R/V Thomas Thompson Cruise Number 40

Station No.	Date	Start Time	Start Latitude	Start Longitude	Max. Depth (meters)
1	13-Oct-94	0240 UTC	16° 00.0860' N	61° 29.9889' E	3973
2	15-Oct-94	1354 UTC	15° 30.0170' N	61° 29.5350' E	1000
3	15-Oct-94	1554 UTC	15° 36.7440' N	61° 23.1320' E	1000
4	15-Oct-94	1851 UTC	15° 50.3220' N	61° 09.0220' E	1000
5-1	15-Oct-94	2055 UTC	15° 43.6080' N	61° 16.2440' E	1000
5-2	15-Oct-94	2212 UTC	15° 43.4890' N	61° 16.0050' E	1000
6	17-Oct-94	1456 UTC	15° 43.3410' N	61° 15.9050' E	1000
7	17-Oct-94	1724 UTC	15° 29.9700' N	61° 16.0900' E	1000
8	17-Oct-94	1918 UTC	15° 23.2130' n	61° 23.0700' E	1000
9	18-Oct-94	1137 UTC	15° 16.0310' N	61° 17.2080' E	1000
10	18-Oct-94	1343 UTC	15° 09.6920' N	61° 09.1830' E	1000
11	18-Oct-94	1844 UTC	15° 16.4220' N	61° 30.0480' E	1000
12	18-Oct-94	2126 UTC	15° 30.4010' N	61° 29.9260' E	1000
13	19-Oct-94	1157 UTC	15° 16.1060' N	61° 44.4050' E	1000
14	19-Oct-94	1410 UTC	15° 09.7510' N	61° 51.0890' E	1000
15	19-Oct-94	1707 UTC	15° 23.2140' N	61° 37.0710' E	1000
16	19-Oct-94	1855 UTC	15° 29.9989' N	61° 44.0770' E	1000
17	19-Oct-94	2045 UTC	15° 36.7140' N	61° 37.0570' E	1000
18	20-Oct-94	1608 UTC	15° 43.2520'N	61° 43.8620' E	1000
19	20-Oct-94	1754 UTC	15° 50.2940' N	61° 51.0270' E	1000
20	20-Oct-94	2010 UTC	16° 02.1850' N	61° 59.9250' E	1000
21	21-Oct-94	0034 UTC	15° 43.5500' N	61° 30.0600' E	1000
22	21-Oct-94	0306 UTC	15° 30.8730' N	61° 31.7510' E	1000
23	21-Oct-94	0433 UTC	15° 31.0720' N	61° 32.6720' E	200
24	21-Oct-94	0534 UTC	15° 31.3230' N	61° 33.7190' E	200
25-2	21-Oct-94	0910 UTC	15° 29.4850' N	61° 32.1450' E	200
26-1	21-Oct-94	1146 UTC	15° 16.0260' N	61° 44.7030' E	300
26-2	21-Oct-94	1210 UTC	15° 16.3110' N	61° 44.9340' E	300
26-3	21-Oct-94	1231 UTC	15° 16.6470' N	61° 44.8980' E	300
26-4	21-Oct-94	1254 UTC	15° 17.2320' N	61° 44.8770' E	300
26-5	21-Oct-94	1317 UTC	15° 17.9140' N	61° 44.8220' E	300
26-6	21-Oct-94	1342 UTC	15° 18.6300' N	61° 44.8700' E	300
26-7	21-Oct-94	1405 UTC	15° 18.6170' N	61° 44.7870' E	300
26-8	21-Oct-94	1428 UTC	15° 20.0480' N	61° 44.7100' E	300
26-9	21-Oct-94	1452 UTC	15° 20.8200' N	61° 44.7180' E	300
26-10	21-Oct-94	1517 UTC	15° 21.6420' N	61° 44.7730' E	300
26-11	21-Oct-94	1539 UTC	15° 22.3370' N	61° 44.7930' E	300
26-12	21-Oct-94	1601 UTC	15° 23.0240' N	61° 44.7880' E	300
26-13	21-Oct-94	1623 UTC	15° 23.6820' N	61° 44.7540' E	300

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26-14	21-Oct-94	1646 UTC	15° 24.3940' N	61° 44.7110' E	300
26-15	21-Oct-94	1709 UTC	15° 25.0930' N	61° 44.5960' E	300
26-16	21-Oct-94	1731 UTC	15° 25.6800' N	61° 44.5600' E	300
26-17	21-Oct-94	1756 UTC	15° 26.5730' N	61° 44.4270' E	300
26-18	21-Oct-94	1822 UTC	15° 27.4960' N	61° 44.3690' E	300
26-19	21-Oct-94	1845 UTC	15° 28.1620' N	61° 44.3430' E	300
26-20	21-Oct-94	1909 UTC	15° 29.0520' N	61° 44.2280' E	300
26-21	21-Oct-94	1937 UTC	15° 30.1610' N	61° 44.1370' E	300
26-22	21-Oct-94	2001 UTC	15° 31.0150' N	61° 44.0890' E	300
26-23	21-Oct-94	2026 UTC	15° 31.9350' N	61° 43.9920' E	300
26-24	21-Oct-94	2050 UTC	15° 32.8240' N	61° 43.9510' E	300
26-25	21-Oct-94	2114 UTC	15° 33.7530' N	61° 43.9229' E	300
26-26	21-Oct-94	2139 UTC	15° 34.6710' N	61° 43.8590' E	300
26-27	21-Oct-94	2205 UTC	15° 35.6980' N	61° 43.7720' E	300
26-28	21-Oct-94	2230 UTC	15° 36.6590' N	61° 43.6930' E	300
26-29	21-Oct-94	2255 UTC	15° 37.6600' N	61° 43.6670' E	300
26-30	21-Oct-94	2320 UTC	15° 38.6590' N	61° 43.6770' E	300
26-31	21-Oct-94	2344 UTC	15° 39.6120' N	61° 43.8170' E	300
26-32	22-Oct-94	0008 UTC	15° 40.5230' N	61° 43.8610' E	300
26-33	22-Oct-94	0032 UTC	15° 41.4360' N	61° 44.0320' E	300
26-34	22-Oct-94	0056 UTC	15° 42.3750' N	61° 44.3730' E	300
26-35	22-Oct-94	0124 UTC	15° 43.5060' N	61° 44.6490' E	300

Appendix 4
Arabian Sea Instrument Summary

Instrument No.	Mooring	Depth (meters)
Brancker Temperature Recorders		
2534	WHOI Central 1	300.00
3259	WHOI Central 1	20.00
3301	WHOI Central 1	90.00
3305	WHOI Central 1	30.00
3662	WHOI Central 1	0.50
3667	WHOI Central 1	1.50
3703	WHOI Central 1	40.00
3761	WHOI Central 1	175.00
3762	WHOI Central 1	2.50
3763	WHOI Central 1	4.50
3836	WHOI Central 1	0.25
3839	WHOI Central 1	2.00
4481	WHOI Central 1	72.50
4483	WHOI Central 1	1.00
4487	WHOI Central 1	60.00
4489	WHOI Central 1	50.00
4491	WHOI Central 1	125.00
4493	WHOI Central 1	225.00
5432	WHOI Central 1	1.50
VMCMs		
VM-011	WHOI Central 1	5.00
VM-015	WHOI Central 1	55.00
VM-016	PCM South	300.00
VM-018	PCM South	500.00
VM-021	PCM South	750.00
VM-025	PCM South	1500.00
VM-033	WHOI Central 1	45.00
VM-037	WHOI Central 1	15.00
VM-038	PCM South	3000.00
VM-039	WHOI Central 1	25.00

Arabian Sea Instrument Summary Continued

Seacats

1179	WHOI Central 1	1.50
357	WHOI Central 1	100.00
994	WHOI Central 1	150.00
992	WHOI Central 1	200.00
993	WHOI Central 1	250.00

MTR

3240	WHOI Central 1	3.50

MVMS

302703-LD	WHOI Central 1	10.00
401405-LD	WHOI Central 1	65.00
500501-USC	WHOI Central 1	35.00
500601-USC	WHOI Central 1	80.00

Appendix 5

Wind Direction Sensor Comparison Tests

Part of the preparation of the meteorological packages includes checking the wind direction sensors. This consists of placing each buoy on a test station that can be rotated through 360° and directing the wind vane to a fixed target at 60° intervals. The direction is then computed from the instrument compass and vane direction data. This procedure was followed both in Woods Hole prior to shipping and again in Muscat on the dock prior to loading the buoys on the ship.

The test site in Woods Hole was located at the southern corner of the Clark South Laboratory parking area. This site showed little horizontal or vertical spatial variation in the magnetic field. The buoys were mounted each in turn on a wooden and masonite turntable, and the direction of a tree near the Clark building was measured from six buoy orientations. At each of the six positions the wind vane was aligned to the tree by eye and locked in position. The data was then read directly from the instrument. In the case of the VAWR the compass and vane positions are added to obtain the wind vane direction in oceanographic convention (i.e., the wind direction of flow from the north is 180°). The magnetic bearing to the tree from the test site is 309.0°.

Selection of a test site in Muscat was limited to the dock area. All the magnetic problems associated with a dock were assumed to be present. Large 40' containers were located near the site and trucks would be passing through the area periodically. A crude survey of the Muscat test site was made using a diver's compass. The direction checks in Muscat were conducted to identify any gross problems that might have occurred in the instrumentation during shipping and should not be considered a calibration since careful selection of the site was not possible. The magnetic bearing to the distant object sited in Muscat was 210°.

A direction comparison test with VAWR V721 WR was completed in Woods Hole on 27 May 1994. The IMET wind module that was deployed on the Arabian Sea surface buoy (WND 104) did not have a direction comparison test completed in Woods Hole. Both units were tested in Muscat, Oman.

In Oman a 5° offset between the VAWR readings and the bearing to the distant object was observed. To compensate for this offset the VAWR vane magnet ring was rotated approximately 5°. After rotation of the magnet ring two buoy orientations were re-checked. Figures A5-1 and A5-2 show the Woods Hole and Muscat results respectively.

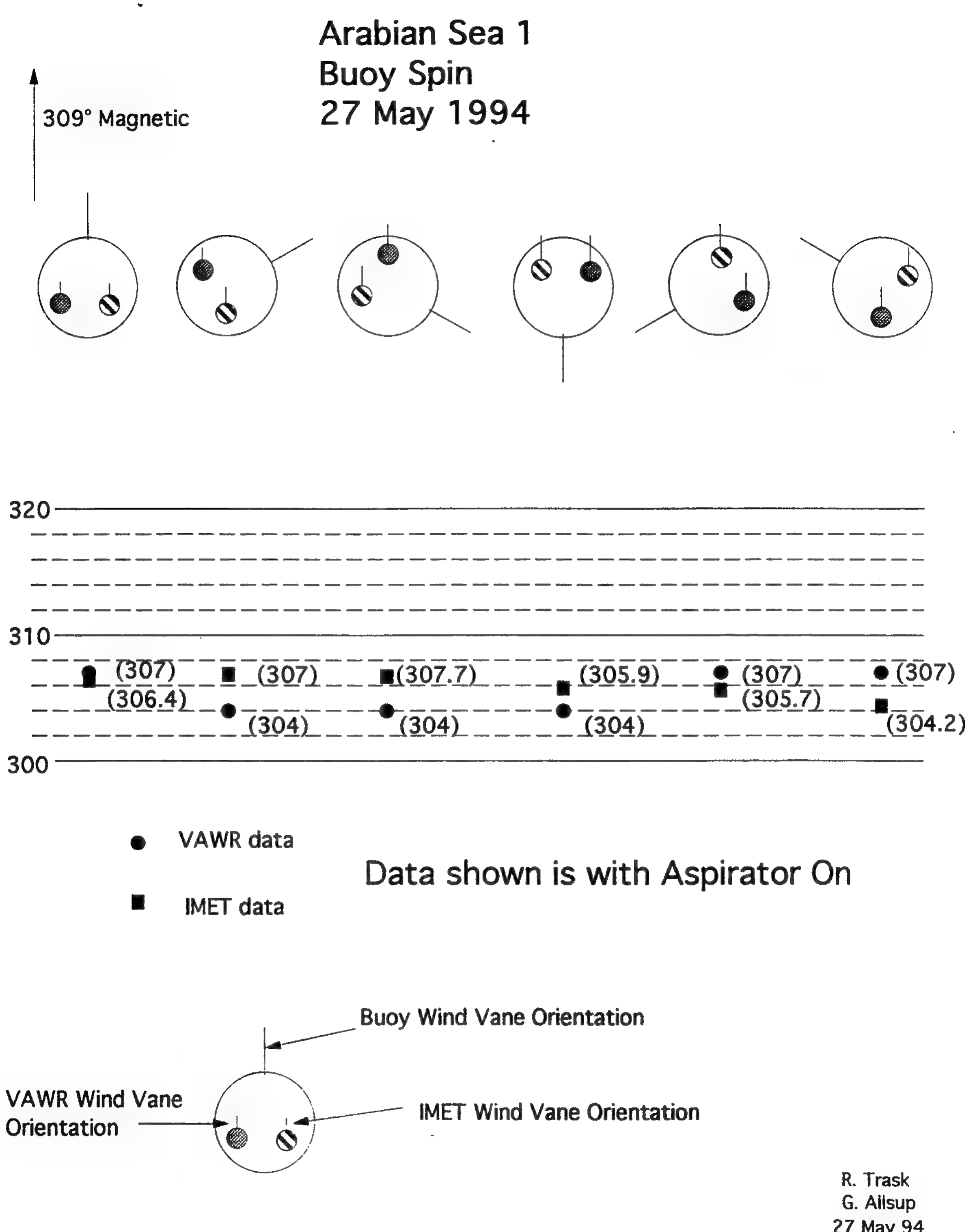

Figure A5-1. VAWR wind direction comparison test conducted at WHOI.

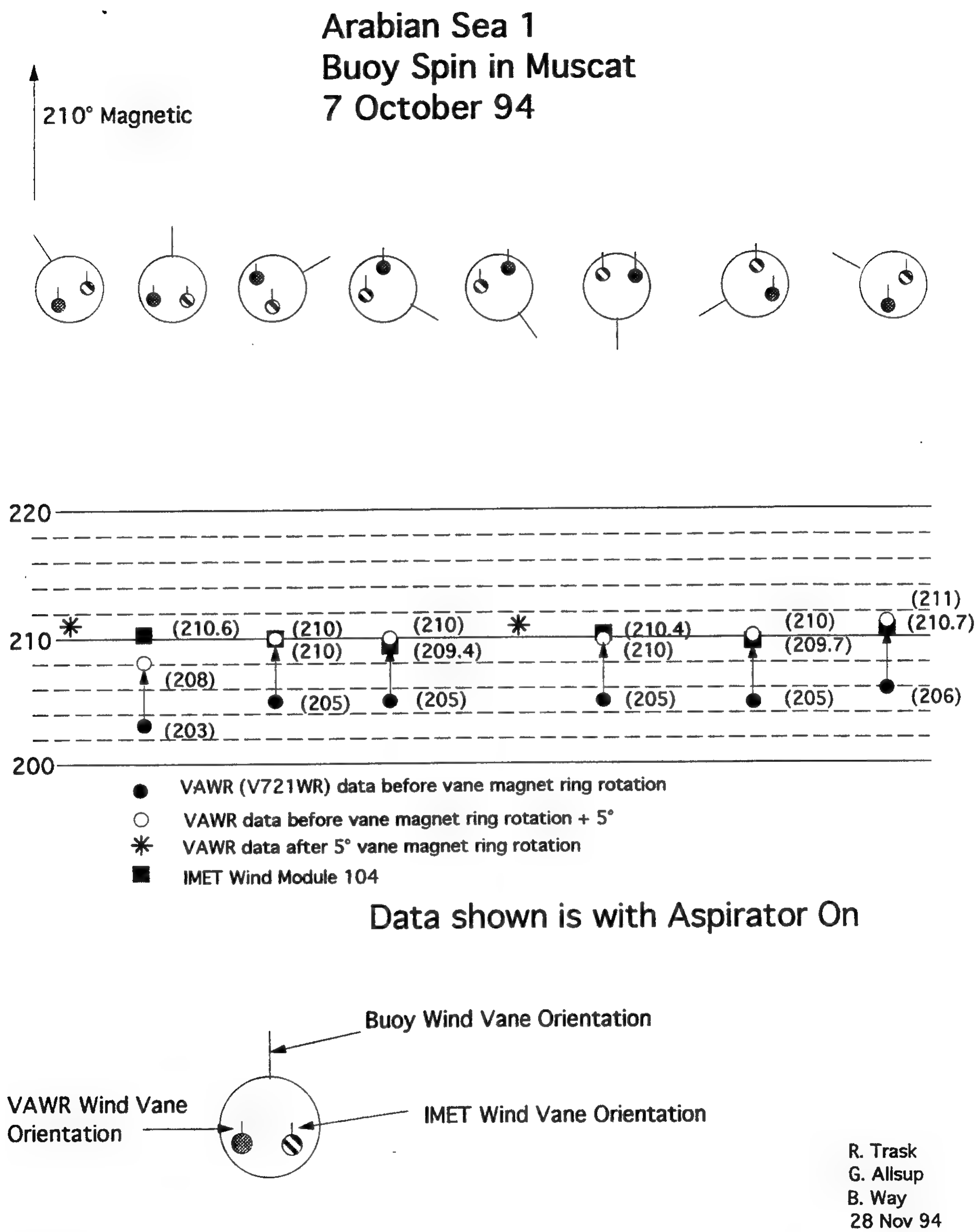

Figure A5-2. VAWR and IMET wind direction comparison test conducted in Muscat, Oman

Appendix 6

VMCM RECORD FORMAT

1. RECORD COUNTER (TIME)

The first 16 bits (4 characters) of data comprise the record number. The counter is incremented once each data record. The first record number is one and is used to initialize the instrument. The data and length of the first record may be invalid and should be ignored. Record two contains data for the first record interval. After 65535 records, the record counter will reset to zero and begin its normal counting.

2. NORTH VECTOR

Each vector is scaled from a 24 bit accumulator and stored in a 16 bit floating-point representation. This vector is the algebraic sum of the NORTH component of current flow from each sample.

3. EAST VECTOR

Each vector is scaled from a 24 bit accumulator and stored in a 16 bit floating-point representation. This vector is the algebraic sum of the EAST component of current flow from each sample.

4. ROTOR 2 (X CURRENT FLOW) (UPPER)

The rotor counts are an algebraic sum of the counts for a record interval. Rotor counts are scaled from a 24 bit accumulator and stored as a 16 bit floating number.

5. ROTOR 1 (Y CURRENT FLOW) (LOWER)

The rotor counts are an algebraic sum of the counts for a record interval. Rotor counts are scaled from a 24 bit accumulator and stored as a 16 bit floating number.

6. COMPASS

The compass field is an 8 bit 2's complement number (-128 to +128 decimal). The stored value is measured at the beginning of the last sample of the record interval.

7. TEMPERATURE

One temperature sample is taken just before the end of the last record interval.

Record interval = 2 seconds to 2 hours
Sample interval = .25 seconds to 2 seconds in quarter second steps

PREAMBLE/	TIME/	NORTH/	EAST/	R2/	R1/	COMPASS/	TEMP./	PARITY
(2)	(4)	(4)	(4)	(4)	(4)	(2)	(4)	(1)

(X) = Number of characters

Appendix 7

Mooring Deployment Procedures and Related Notes

W.Ostrom

The Arabian Sea surface moorings deployed from the R/V *T.Thompson* were set using the UOP two phase mooring technique. Phase 1 involved the lowering of approximately 40 meters of instrumentation over the port side of the ship and phase 2 the deployment of the surface buoy into the sea. The benefits from lowering the first 40 meters of instrumentation is three fold in that: (1) it allows for the controlled lowering of upper instrumentation; (2) the suspended instrumentation, attached to the buoy's bridle acts as a sea anchor to stabilize the buoy during the deployment of the buoy; and (3) the 80 meter length of paid out mooring wire provides adequate scope for the buoy to clear the stern of the ship without capsizing or hitting the ship.

The basic deck equipment and deck layout is illustrated in Figure A7-1. The mooring gear used for deployment of the surface moorings includes: the Lebus winch system, O1 level crane, HIAB crane, Yale grips and the standard complement of chain grabs, stopper and slip lines.

The personnel utilized during the first phase of the operation were: a deck supervisor, 2 Lebus winch operators, 3 mooring wire handlers, 3 slip line handlers, crane-whip man, quick release hook man, and a crane operator. Figure A7-2 illustrates the positioning of personnel during the instrument lowering phase.

For this narrative the WHOI surface mooring (Figure A7-3) is used to describe the deployment procedures of all the surface moorings from the *Thompson*. Prior to the deployment of the UOP discus mooring, a 200 meter length of 3/8" diameter wire rope was measured and 5 Yale grips were woven at 43 m, 34 m, 31 m, 28 m, and 24 m from the end of the swage fitting. (Yale grips are a multi-strand Kevlar eye splice that can be spliced onto wire or line mid-span.) The grips provide the wire handler at the rail a better holding point on the hauling wire during the instrument lowering phase of the deployment. This wire shot, or hauling wire, was pre-wound onto a wooden reel, with the Yale grips on the top of the reel. The reel was secured to the Lebus spooler and the bitter end of the wire paid out and reeved 5 wraps around the Lebus capstan winch. The hauling wire was then paid out to allow its bitter end to be passed out through the center of the A-frame and around the aft port quarter and up forward along the port rail to the instrument lowering area (Figure A7-2).

The three hauling wire handlers were positioned around the aft port rail. Their positions were in the center of the A-frame, aft port quarter, and approximately 8 meters forward along the port rail. The wire handlers job was to keep the hauling wire from fouling in the ship's propellers.

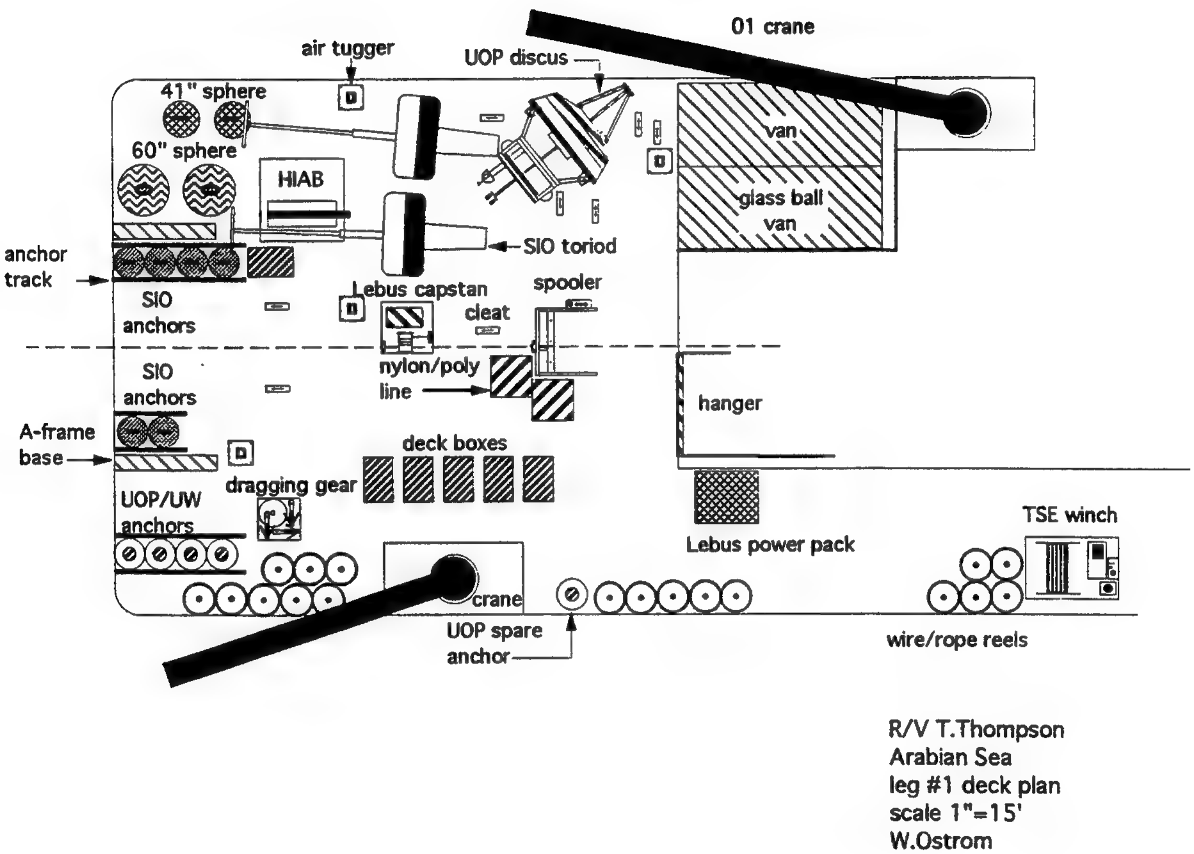

Figure A7-1. Deck Plan of the R/V T.Thompson during cruise number 40.

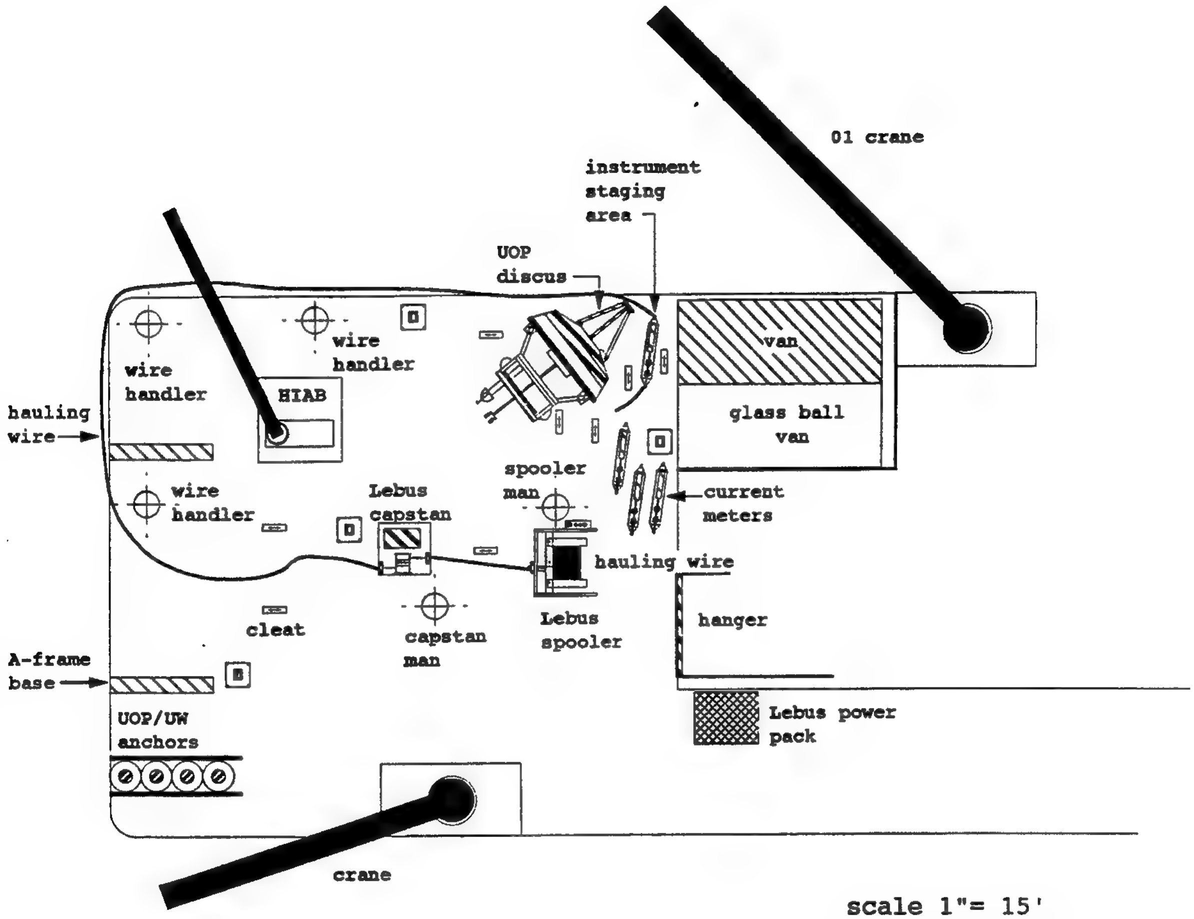

Figure A7-2. Personnel work stations during surface buoy deployments.

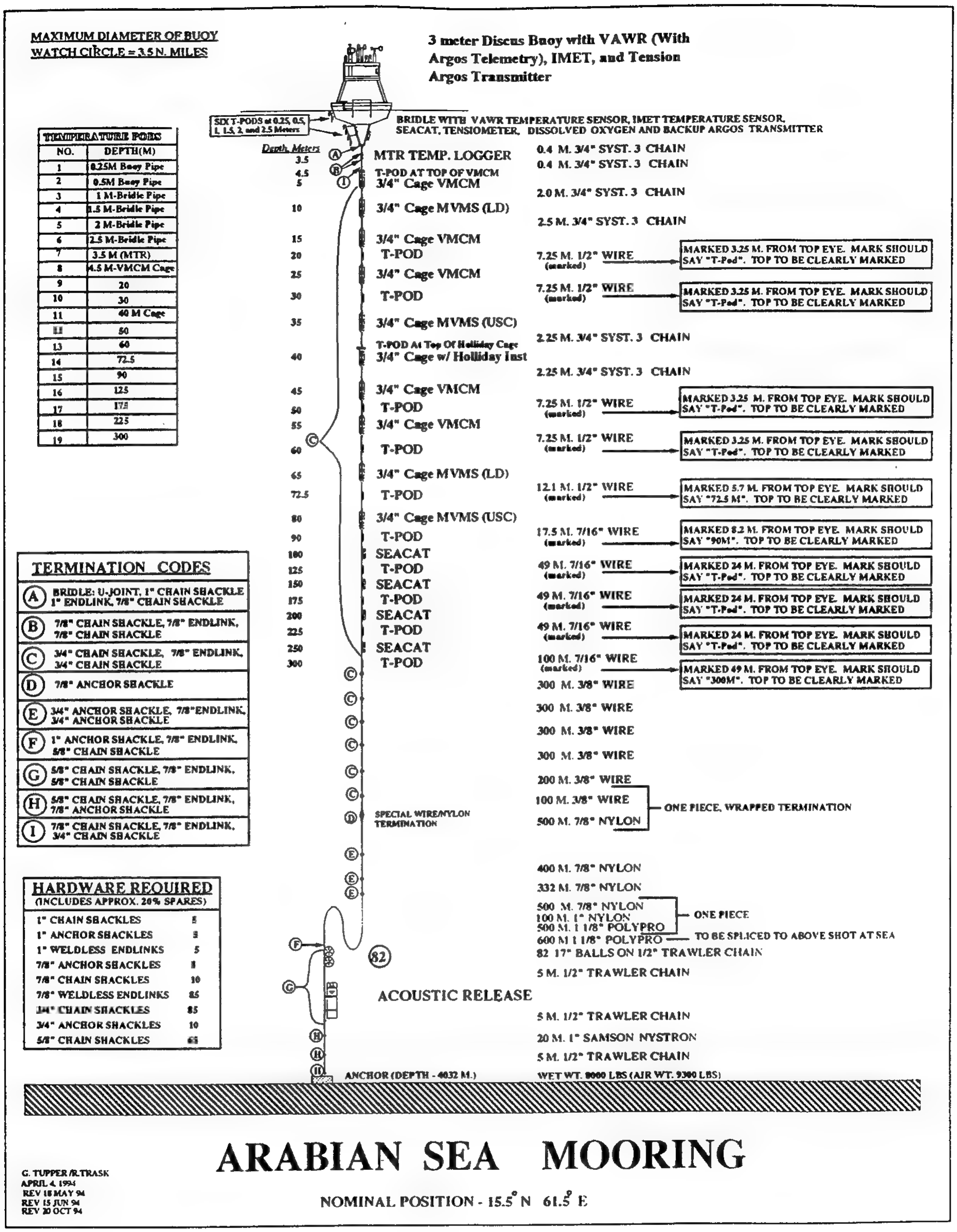

Figure A7-3: WHOI surface mooring schematic.

The HIAB crane located on the fantail's port side was used as an outrigger hooking the last Yale grip to a Release-A-Matic quick release hook which was secured to the HIAB boom. The crane's boom was articulated so that it would reach 10 ft over the port side. The aft port quarter wire handler was responsible for attaching the last Yale grip to the hook and releasing this grip and hauling wire once the discus had been deployed and had drifted clear of the ship's propellers.

Prior to the start of the operation the ship's bow was positioned up wind with minimal way during the instrument lowering phase. The ship's 01 level crane used a single whip during the instrument lowering. The crane was extended out so that there was a minimum of 10 meters of free whip hanging over the instrument lowering area. The longest wire segment to be raised in the upper 35 m of the UOP mooring was a 7.25 meter shot of 1/2" diameter wire rope.

The Lebus winch was operated by two operators, a capstan man and a spooler man. Their duties entailed the paying out of the hauling wire at a similar speed to that of the 01 level crane's whip. The instrument lowering commenced by shackling the bitter end of the hauling wire to the lower end of 2.25 meter length of 3/4" chain that is shown below the 35 meter instrument. The crane whip was hooked near the top end of the chain shot using a 3/4" chain grab and sling. This was done with the 01 crane in the extended position. The crane whip then raised the chain until the entire length was vertical and approximately .5 meter off the deck. The crane was instructed to swing outboard one meter to clear the ship's side and slowly lower its whip and attached chain down into the water. The Lebus winch simultaneously paid out the hauling wire. The wire handlers positioned around the stern tended the hauling wire easing it over the port side and allowing only enough wire over the side to keep the lowered shot of chain vertical in the water. The chain was stopped off when the end was .5 meters above the ship's deck. The crane was then directed to swing slightly inboard. A stopper line with 3/4" chain grab was hooked into the loose end of the chain and secured to a deck cleat. The whip was then lowered transferring the tension to the stopper line.

The next segment in the mooring to be lowered was the 35 meter MVMS. This instrument was brought into the instrument lowering area with its bottom end pointing outboard so that it could be shackled to the top of the stopped off chain shot. The next mooring component above the MVMS was a 7.25 m shot of 1/2" wire rope. One end of this wire was shackled to the top of the MVMS. The loose end of the wire, fitted with a 3/4" shackle and a 7/8" end link, was hooked onto the crane whip hook. The crane whip was then raised taking with it the wire and instrument into a vertical position, .5 m off the deck. Once the crane's whip had taken the load of the mooring components and they were hanging over the side, the stopper line was slackened and removed. The crane was then swung outboard and the whip lowered. The Lebus winch slowly paid out the hauling wire.

The operation of lowering the upper mooring components in conjunction with the pay out of the hauling wire was repeated up to the 3/4" chain shot with the MTR

temperature logger. At this stopping point the chain segment attached to the MTR was stopped off to the deck with a chain grab leaving enough slack in the assembly to be shackled to the discus universal joint attached to the bridle.

At this point in the deployment the last Yale grip was hooked into the quick release hook which hung from the HIAB crane boom. The crane then extended outboard over the aft port rail keeping the hauling wire well away from the side of the ship.

The second phase of the deployment was the launching of the discus buoy. There were 4 slip lines rigged to the discus to maintain constant swing control during the lift. One was positioned on the bridle, two on the tower bails and one on the buoy deck bail (Figure A7-4). The 30 ft bridle slip line was used to stabilize the bridle and allow the hull to pivot on the bridle's apex at the start of the lift. The two 60 ft tower bail slip lines were rigged to check tower swing as the hull swung outboard. The 60 ft buoy deck bail slip line was the most important of all the slip lines. This line prevented the buoy hull from spinning as the buoy settled out in the water. This is important so that the quick release hook, hanging from the crane's whip, could be released without fouling. The buoy deck bail slip line was removed just following the release of the discus into the sea. One additional line called the whip tag line was used in this operation. This tag line was 60 ft in length and was tied 20 ft up on the crane whip. The whip tag line kept the whip away from the tower's meteorological sensors once the quick release hook had been pulled free and the discus was cast adrift.

The personnel utilized for this phase of the operation included a deck supervisor, two Lebus winch operators, two hauling wire handlers, four slip line men, a crane operator, a crane whip tag line man and a quick release hook man.

With all four slip lines in place the crane was directed to swing over the discus buoy. The extension of the crane's boom was approximately 60 ft. The crane's whip was then lowered to the discus and the quick release hook attached to the main lifting bail. Slight tension was taken up on the whip to take hold of the buoy. The chain lashings, binding the discus to the deck were removed. The stopper line holding the suspended 40 meters of mooring string up to the apex of the discus bridle was eased off to allow the discus to take on that hanging tension. The discus was then raised up and swung outboard as the slip lines kept the hull in check. The bridle slip line was removed first followed by the outboard tower bail and then the inboard tower bail. Once the discus had settled into the water (approximately 20 ft from the side of the ship), and the release hook had gone slack the quick release hook man pulled the trip line and cleared the whip away from the buoy (forward) with the help of the whip tag line man. The tag line to the buoy deck bail should be cleared at about the same time the quick release hook is tripped or slightly after. If the discus were released prior to the buoy settling out in the water the tower could swing into the whip and cause potential damage to the tower sensors. The ship then maneuvered slowly ahead to

Figure A7-4

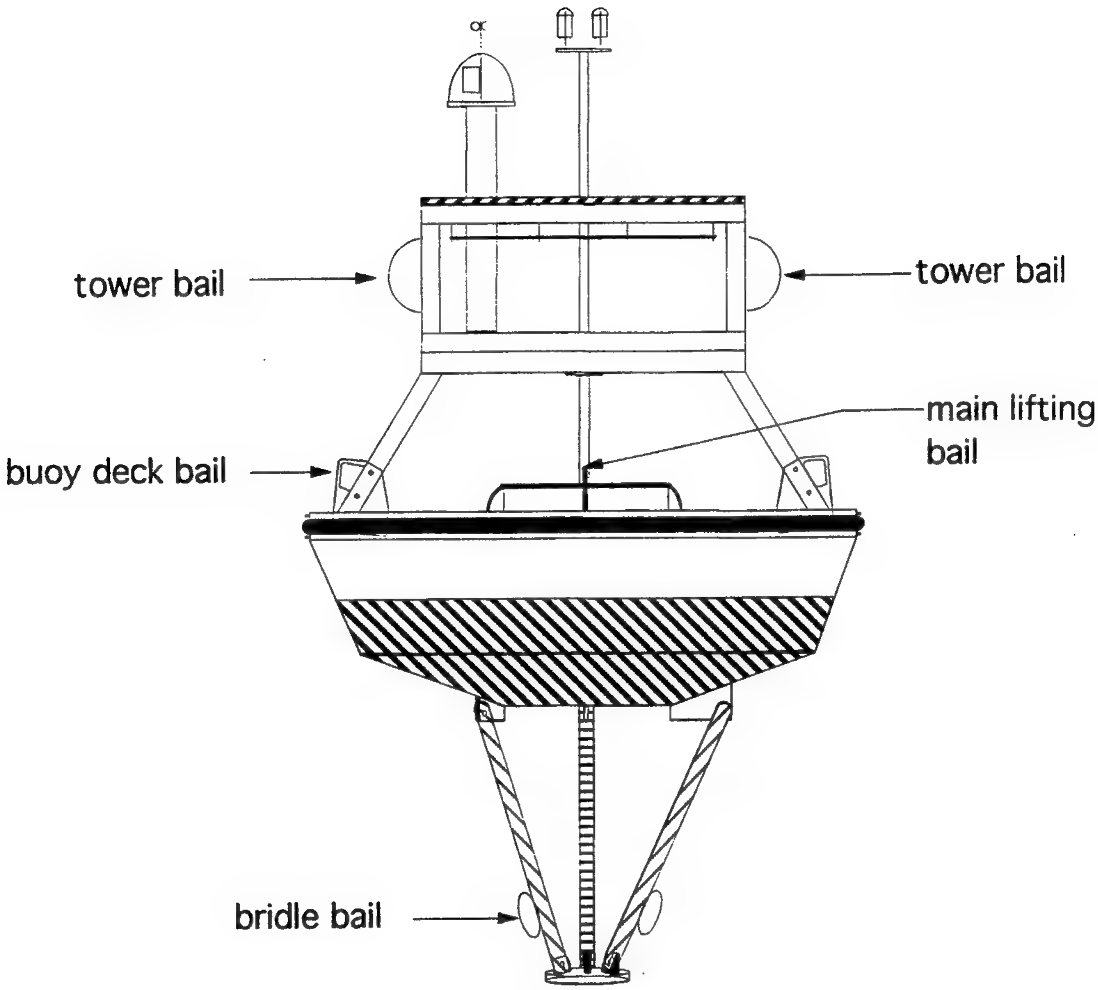

Figure A7-4. UOP Discus buoy bail configuration.

allow the discus to pass around the stern of the ship. The HIAB crane holding the Yale grip on the hauling wire was cast off only after the discus had drifted aft of the ships propellers.

The Lebus was paid out slowly to give additional scope to the discus as the mooring straightened out behind the ship. Once this had occurred the hauling wire was hauled in up to the bottom end of the 2.25 m shot of 3/4" chain (Figure A7-2) where it was stopped off at the transom. The hauling wire was unshackled from the chain and removed. The next instrument was brought out and shackled to the bitter end of the chain. At this point the remainder of the mooring was deployed using the WHOI Buoy Group's winch to deck stopper technique (Heinmiller, 1976).

PCM

Due to high seas and wind conditions the second setting of the northern University of Washington profiling current meter (PCM) mooring (Figure A7-5) required special handling procedures for the PCM, guideline and top 41" diameter steel sphere. The equipment utilized for this lift included the Lebus winch system, the HIAB crane with Gifford mooring block, a 1000 lb line pull air tugger and one fair lead block hung on the A-frame.

The air tugger's winch line was first reeved up through the A-frame block and down to the 41" sphere, which was positioned on the inboard port side of the A-frame. A quick release hook was shackled to this line and the hook attached to the sphere lifting bail. The 10 ft length of 5/8" chain which was shackled to the bottom of the 41" sphere was faked out on deck in the center of A-frame (Figure A7-5).

The PCM, in its storage cage, and coiled guideline were then carried out on deck and positioned in the center of the A-frame next to the 41" sphere. The HIAB crane boom was swung over between the PCM and the front of the Lebus capstan winch. The Gifford block was then hooked onto the crane boom hook. The bottom end of PCM's guideline was passed through the Gifford block. The wire was then reeved around the Lebus capstan drum with 5 wraps and spooled onto a wooden reel secured to the winch spooler. The PCM in its storage cage was manually lifted into a vertical position near the faked out 5/8" chain attached to the sphere. The Gifford block was raised over the PCM and the Lebus winch slowly wound up the loose slack in the guideline until the top guideline stop had engaged with the PCM stem and had raised the instrument and cage up 6" from the deck. The storage cage was then removed. The shackle connection between the 5/8" chain and the top shock absorber was made up. The air tugger was hauled in and raised the 41" sphere clear of deck. The A-frame shifted slowly outboard bringing the sphere clear of the ship's transom. The sphere was lowered so that it was parallel to the transom. The HIAB crane then extended aft out over the stern of the ship lifting the PCM outboard of the ship hull. The air tugger commenced to lower the sphere into the sea. The Lebus then slowly followed lowering the PCM. With the ship steaming at approximately 1 knot through the water, the PCM was deployed within seconds of the release of the steel sphere. The

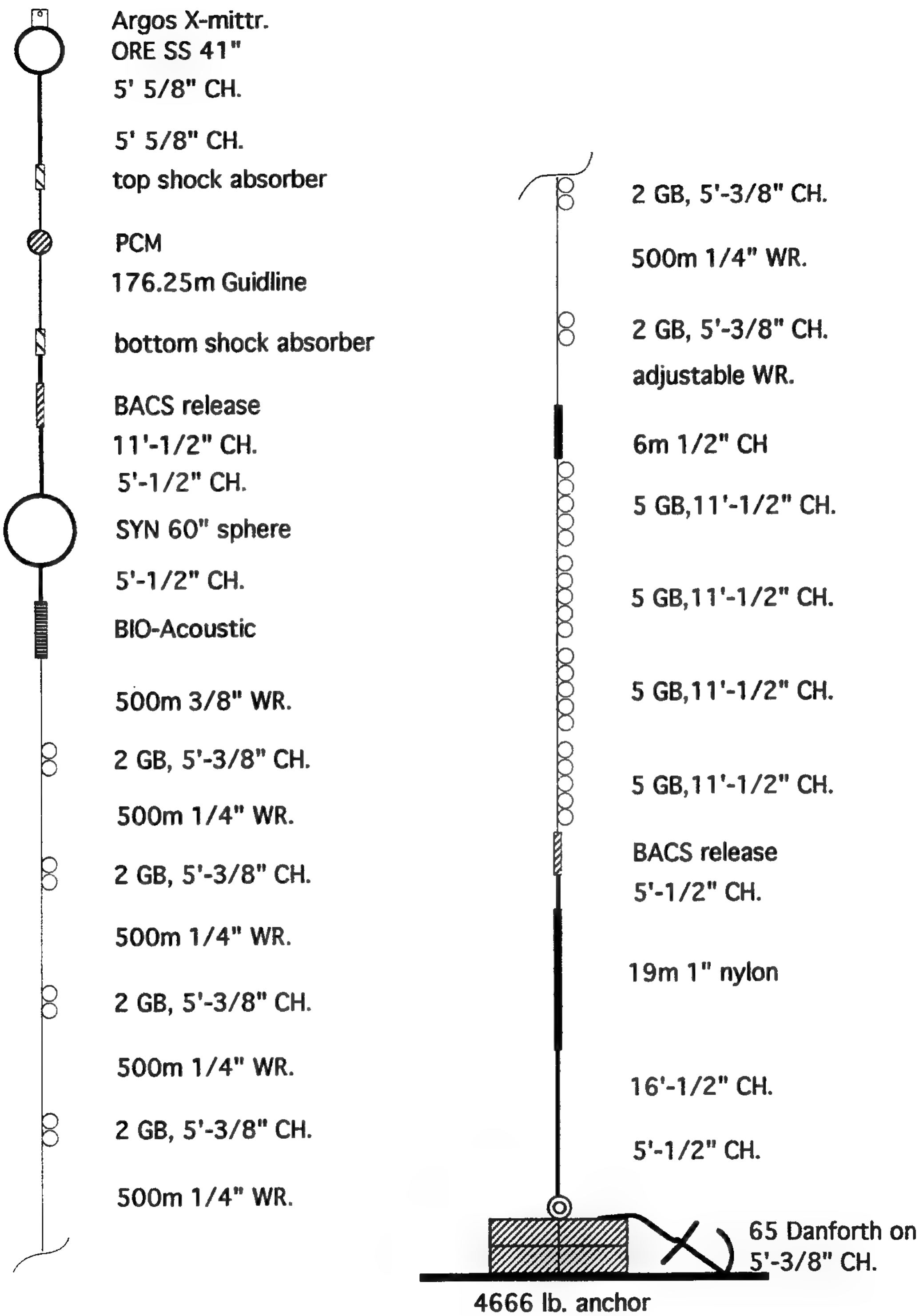

Figure A7-5. PCM Mooring Schematic

guideline was then slowly paid out as the ship made way through the water. Once the entire guideline had been deployed the BACS release and mooring chain were shackled into the mooring string. These components were paid out and stopped off leaving approximately 2 meters of loose chain on deck.

As with the deployment of the PCM and 41" sphere, the 60" diameter 2000 lb syntactic foam sphere and bio-acoustic instrument were launched simultaneously because of their close proximity. The ship's trawl wire was used to shift the sphere into the center of the A-frame near the stopped off mooring chain. The loose chain was then shackled to the top 5 foot section. The lifting line of another air tugger located on the starboard side of the A-frame was reeved through the starboard A-frame rigging block and brought down to the deck. The top of the bio-acoustic instrument was positioned so that the loose end of the bottom chain shackled to the sphere could be made up. The next component following the bio-acoustic instrument, was a 500 meter shot of 3/8" diameter wire rope. In the original design this shot of wire was going to be 1/4" diameter wire, but due to the high sea conditions there was concern of shock loading the wire from wave surge. The bitter end of the 500 meter shot was reeved around the Lebus 6 wraps and shackled to the bottom end of bio-acoustic instrument. The air tugger was rigged with a small quick release hook and attached to the bottom of the instrument. It was then raised up and over the starboard aft rail and was lowered parallel to the ship's transom. A quick release hook was fitted to the end of the trawl wire and hooked to the lifting bail on the sphere. Tension was taken up by the trawl winch lifting the sphere. The A-frame shifted outboard and the trawl wire slowly paid out, lowering the sphere. As the sphere submerged the air tugger lowered the bio-acoustic instrument which was cast off just after the sphere was released. Next approximately 30 meters of 3/8" wire rope was paid out quickly over the transom to give the sphere some distance between the ship's pitching and the passing waves. The remainder of the mooring was deployed using the WHOI Buoy Group's winch to deck stopper technique (Heinmiller, 1976).

SIO Anchor Deployments

The Scripps Institution of Oceanography (SIO) had 2 surface moorings which were deployed during the cruise. The 2 phase UOP procedure utilized for the discus deployment was also implemented for the SIO moorings. The anchor deployment of the SIO moorings however was quite different from the WHOI discus mooring. The discus mooring anchor was a single cast iron cylinder weighing 9300 pounds whereas the SIO anchors were composed of two bridled stacks of railroad wheels each stack weighing 2600 pounds.

The standard UOP procedure for anchor deployments entailed that following the paying out of the anchor pennant, the inboard end of the pennant would be slipped out using a slip line transferring the mooring tension to the anchor. The anchor would be sitting on a steel flip plate that would have a chain bridle attached to its forward end. This chain bridle would in turn be hooked to a hauling wire or crane whip. Once the

slip line had been cleared and the towed mooring was in line with the anchor the hauling wire would take tension and raise the flip plate up on edge 6" to 8". The anchor would then slide off the flip plate and over the stern completing the mooring deployment.

The SIO anchors because of their large size were deployed in line fore and aft through the A-frame. The anchors were positioned in steel angle anchor tracks that were bolted down to the ship's deck. These anchor tracks prevented the anchors from swinging into the A-frame while they were being lifted. There were two track assemblies located on the inboard port and starboard side of the A-frame. Each SIO mooring had its own anchor track.

The ship's trawl wire reeved through a rigging block inside the A-frame was used to lift the dual anchors up and outboard aft of the ship. The SIO group provided a special quick release hook (used primarily in the West coast fishing trade for lifting and releasing seine trawls) for the deployment of their anchors. The standard Release-A-Matic hooks used in the buoy deployments would not work well in this application because the angle of the trip line for the anchor deployments would be close to vertical. The SIO hook conversely works best when the trip line is near parallel to the lift line.

Steps leading to the dual anchor deployment up to the actual lifting of the SIO anchors are identical to the UOP procedures. The trip line of the SIO anchor release hook was first pre-measured so that the anchors would be submerged just at the surface when the hook would be released. The trip line was then cleated at the pre-measured point so that once the anchors were lifted the operation would not rely on personnel to release them. The A-frame was shifted outboard and the trawl wire was brought up lifting the anchors and drawing them aft. Once the anchors cleared the stern the trawl wire was lowered. As the anchors were lowered the trip line became taught which activated the release hook and dropped the anchors.

Miscellaneous notes

During all the deployments a digital tachometer, Ametek model #1726, was used in the calculation of the mooring pay out speed verses the ship's speed through the water. This tool was used as a check to see that the mooring was always being towed slightly during the deployment. The tachometer utilized a rotating wheel which was manually placed against the inside circumference of the Lebus capstan drum. The selected readout from the tachometer was in miles per hour. Table A7-1 shows for a given ship's speed the corresponding tachometer reading. The tachometer reading takes into consideration the differences between the inside circumference of the Lebus drum versus the outside circumference and also differences between nautical mile versus statute mile. In addition the tachometer readings are reduced by approximately 10% to insure that the payout rate is slightly less than the ship's speed through the water.

Paint test

The bottom of the UOP discus buoy hull was used as a test bed for a non-toxic, anti-corrosive, anti-fouling paint called Chemotex. The Chemotex product will be compared with the traditionally used Amercoat 635 tributyltin antifouling paint. There were 5 (12" x 12") test areas masked around the chine of the buoy hull (Figure A7-6). These test patches were first coated with a barrier coat of Ameron Amerlock #400, a high build epoxy, against the aluminum hull. Half of the surface area of the test patches were left uncoated and will be a control surface. The other half of the test area was coated with 6 mils, (2 coats) of Chemotex. The remainder of the hull was coated with 2 x 3 mil thickness of Amercoat 635.

Table A7-1. Winch payout meter readings for different ship speeds

Ship's Speed (knots)	**Payout Meter Reading *** (miles/hr)
0.25	0.24
0.5	0.49
0.75	0.73
1	0.97
1.25	1.21
1.5	1.46
1.75	1.7
2	1.94
2.25	2.19
2.5	2.43
2.75	2.68
3	2.92

* 10% less then ship's speed
Takes into consideration:

Nautical mile vs statute mile

10% reduction to prevent paying out faster then ship's speed.

Winch drum I.D. vs drum O.D.

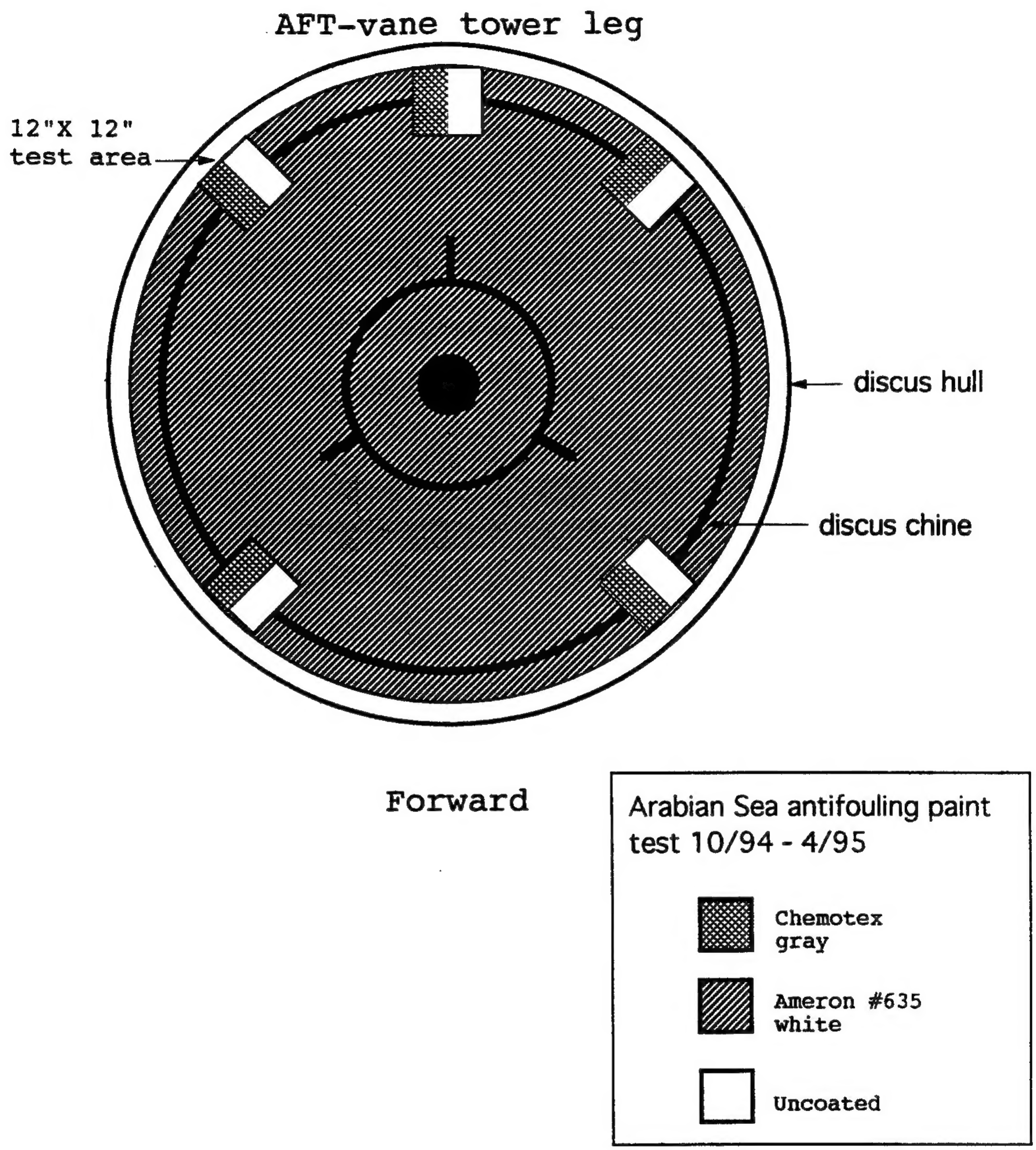

Figure A7-6. Buoy hull antifouling paint test locations.

Appendix 8

Deployment information about WHOI Instrumentation on the University of Washington PCM moorings.

Southern PCM Mooring
Deployed: 19 October 94
Position: 15°16.37'N, 61°44.07'E

ITEM	INST NO.	TIME OVER (UTC)	NOTES
T-POD	3265	0202 UTC	Attached to upper sphere
T-POD	2537	0329 UTC	At ~250 m
VMCM	VM-016	0341 UTC	Bands off at 0338 UTC
VMCM	VM-018	0407 UTC	Bands off at 0405 UTC
VMCM	VM-021	0427 UTC	Bands off at 0425 UTC Antifouling paint test
VMCM	VM-025	0457 UTC	Bands off at 0455 UTC
VMCM	VM-038	0549 UTC	Bands off at 0547 UTC

Northern PCM Mooring
T-POD number 3279 was mounted on the top sphere (intended to be at 20 meters depth) and deployed on 20 October 94 at 0153 UTC. It was recovered at 0240 UTC so that the ship could be repositioned to a new deployment start position. T-POD 3279 was then redeployed at 0542 UTC.

T-POD 2541 was deployed at 0635 UTC. It was intended to be at 250 meters depth. (Actual depths are approximately 15–20 meters less.)

After receiving information that the top sphere was occasionally on the surface the northern PCM mooring was recovered on 22 October 94.
T-POD 3279 was out of the water at 1054 UTC and T-POD 2541 was out of the water at 1114 UTC.

The northern PCM mooring was re-deployed on 23 October 94. T-POD 3279 was again deployed on the top sphere at 0221 UTC and T-POD 2541 was in the water at 0310 UTC.

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16. Abstract (Limit: 200 words)

An array of surface and subsurface moorings were deployed in the Arabian Sea to provide high quality time series of local forcing and upper ocean currents, temperature, and conductivity in order to investigate the dynamics of the ocean's response to the monsoonal forcing characteristic of the area. The moored array was deployed during R/V *Thomas Thompson* cruise number 40.

One Woods Hole Oceanographic Institution (WHOI) surface mooring, two Scripps Institution of Oceanography (SIO) surface moorings and two University of Washington (UW) Profiling Current Meter moorings were deployed. The moorings were deployed for a period of one year beginning in October 1994 as part of the Office of Naval Research (ONR) funded Arabian Sea experiment. Two six month deployments were planned. The moorings were deployed at 15.5°N 61.5°E (WHOI), 15.7°N 61.3°E (SIO), 15.3°N 61.3°E (SIO), 15.7°N 61.7°E (UW), and 15.3°N 61.7°E (UW).

The WHOI surface mooring was outfitted with two meteorological data collection systems. A Vector Averaging Wind Recorder (VAWR) and an IMET system made measurements of wind speed and direction, sea surface temperature, air temperature, short wave radiation, long wave radiation, barometric pressure, relative humidity and precipitation. Subsurface instrumentation included Vector Measuring Current Meters (VMCMs), Multi-Variable Moored Systems (MVMS), conductivity and temperature recorders and single point temperature recorders.

Expendable bathythermograph (XBT) data and CTD data were collected while in transit to the site and between mooring locations.

This report describes in a general manner the work that took place during R/V *Thomas Thompson* cruise number 40 which was the initial deployment cruise for this moored array. A detailed description of the WHOI surface mooring and its instrumentation is provided. Information about the XBT and CTD data collected during the cruise is also included.

17. Document Analysis a. Descriptors

air-sea interaction
moored instruments
Arabian Sea

b. Identifiers/Open-Ended Terms

c. COSATI Field/Group

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